Video Target Practice

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1.0 Overview

The goal of this project is to design and implement a video game system that used a light-gun to read game information from the screen. The overall system layout and design is broken up into the several parts as seen in Figure 1.

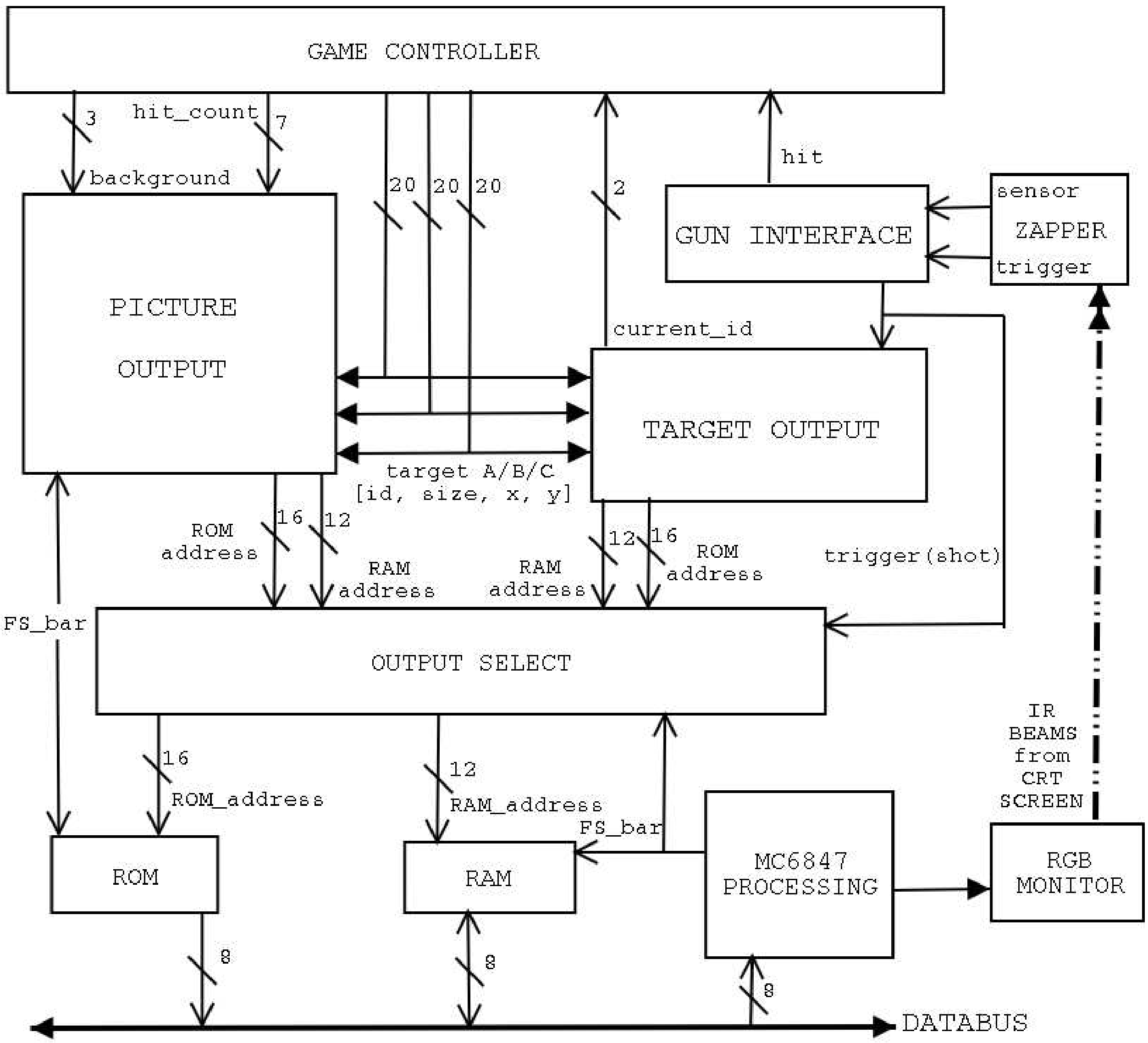


Figure 1. Overall System Layout and Design. The Game Controller takes input from the system to run the game. The Output Select determines whether the system is displaying from the normal Video Output or the Targeting Output. The Zapper and Gun Interface read the display information from the RGB monitor controlled by the MC6847 processing circuits.

The game is played by using the 1985 Nintendo Zapper to shoot targets on an RGB CRT monitor. When the player accurately shoots one of three possible targets on the game screen, the target that has been hit is removed, and the game score is incremented by one. The targets follow and arching pathway across the game screen and progressively get smaller to give the illusion that they are flying away from the player. There are four levels with forty-four possible targets.

2.0 The Nintendo Zapper Interface

The interface between the cathode ray tube (CRT) screen and the Nintendo Zapper is the pivoting technology for this project. The Zapper is equipped with a photo-diode and and IR preamplifier that detects infra-red characteristic beams generated by the electron gun that escaped from the CRT through the phosphorous screen. Figure 2 shows and internal view of the Zapper.

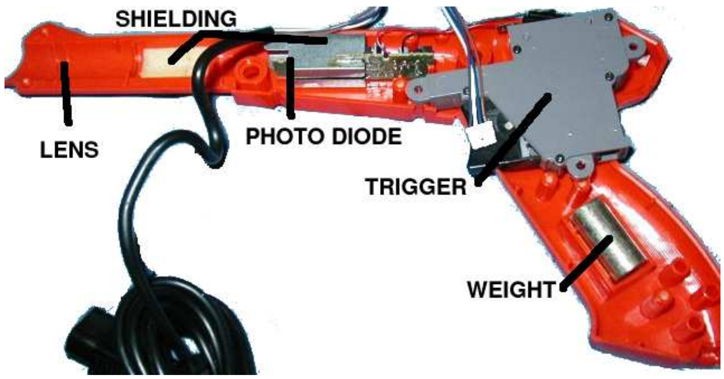


Figure 2. Internal Nintendo Zapper. The lens, shielding, and photo-diode are used to filter and detect IR beams from the CRT accurately up to distances of seven feet.

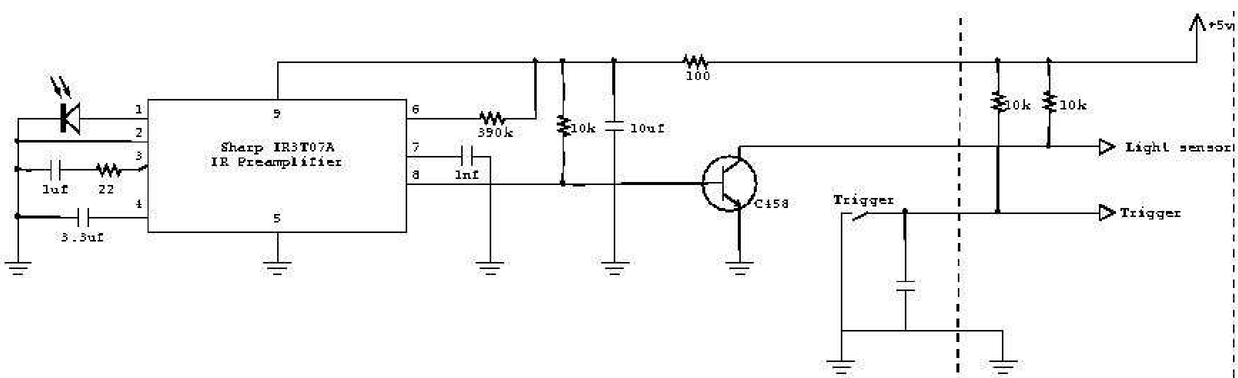


Figure3. Internal and Interface Schematic Diagram. The photo-diode at the top-left of the diagram is used by the IR Preamplifier to detect light beams characteristic of a CRT. The transistor and trigger-switch pull down the sensor and trigger signals that must be connected to 5 volts through 10K resistors in order to work properly. From reversed engineered schematics: Nintendo Entertainment System, Stock # 18-600. Electronics Corp. 1992.

There are four wires that connect to the Zapper, one each for power, ground, sensor, and trigger. The internal and interface schematic is shown in Figure 3. The biggest secret for interfacing the hardware is that the sensor and trigger signals coming from the Zapper are not self-generating. To interface to the Zapper, two 10K pull-up resistors must connect the sensor and trigger signals to the 5 volt power supply. The Zapper pulls the voltage down using a transistor for the sensor and a push-switch for the trigger.

The Gun Interface modules processes the signals coming from the Zapper and puts them in a form more readily usable by the rest of the system. The trigger signal coming from the gun is an active low signal that stays low for approx. 50 milliseconds when the trigger is pulled once. The sensor signal is an active high signal that generates 5 millisecond pulses whenever is senses the light from the CRT. These raw signals can be seen in Figure 4. The Gun Interface modules puts these signals into active-high signals that are sustained longer and for a constant amount of time. It also adds some filtering to ensure accurate results. The formated signals can be seen in Figure 5.

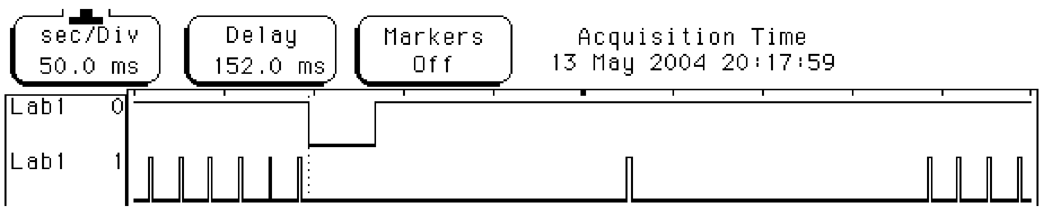


Figure 4. Zapper Signals. Lab1-0 is the trigger. Lab1-1 is the sensor. The trigger goes low for anywhere between 50 to 100 milliseconds when pressed once. The sensor signals generates short pulses when it detects light from the CRT.

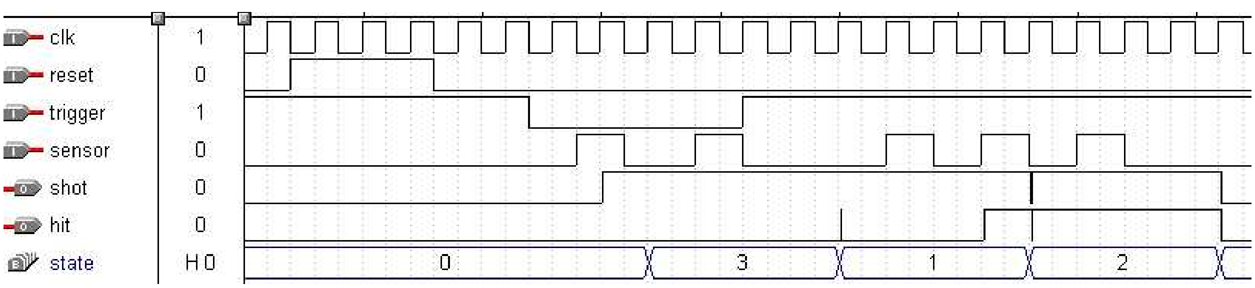


Figure 5. Processed Gun Signals. The trigger and sensor signals are processed in to shot and hit signals. When the trigger is pressed, the shot signal will go high for 320 milliseconds. In state three, the sensor signal is filtered out to allow the time for the screen to blank before detecting hits. State one listens for the sensor, and when it is detected, the hit signal goes high and waits in state two until the trigger signal comes down.

The shot signal is sent to the Targeting Mode Controller and to the Output Selector to let them know when to enter targeting mode. As long as the shot signal is high, the Output Selector gives addressing control to the Targeting Mode Controller. The hit signal is given to the Game Controller in conjunction with a target ID from the Targeting Mode Controller module.

3.0 Targeting

To detect and signal hit targets when then Zapper is triggered, the game deviates from its normal video display mode and enters Targeting Mode. The module that handles video in this mode is the Targeting Mode Controller. This controller proceeds by first blanking out the entire screen and then sequentially drawing white boxes in the places where the targets were in the normal video mode. The inputs and drawing signals for this module can be seen in Figure 6.

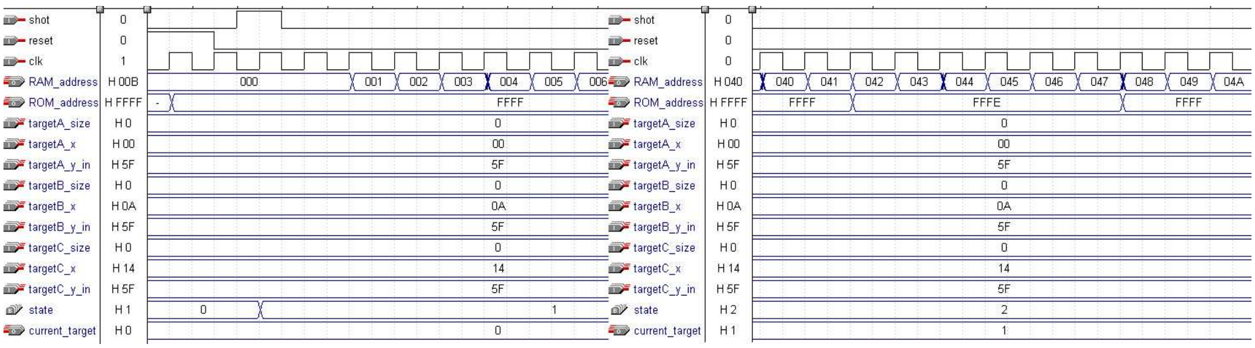


Figure 6. Targeting Mode Controller Inputs and Drawing. When the module hears the shot signal, it begins by blanking the screen for 80 milliseconds. The ROM address 0xFFFF contains all black pixels. It then proceeds to draw each target in white sequentially for 80 milliseconds each. When it gets to a RAM address were a target is to be drawn, the ROM address changes to 0xFFFE which contains all white pixels.

While the controller is drawing each white target-box, it is outputting the current_target ID to the Game Controller. The Game Controller is also listening to the Gun Interface for the hit signal all the time. When it hears the hit signal during a non-zero ID, it removes the target with the current_target ID from the screen. Thus, the system is able to recognize which target is being hit and when it is being hit. The timing analysis for the Zapper and Targeting Mode is shown in Figure 7.

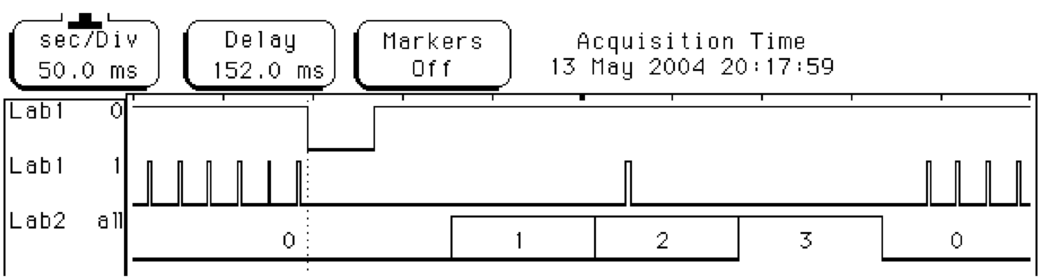


Figure 7. Real-Time Targeting Analysis. This is perhaps the most important analysis of the system. Lab1-0 is the Zapper trigger. Lab1-1 is the Zapper sensor. Lab2 is the current_id bus from the Targeting Mode Controller.

When the trigger is pressed, the Targeting Mode Controller blanks the screen for 80 milliseconds. During the first part of this time, the Gun Interface filters out any sensor signals that may be charged from the previous video screen. If the Zapper detects CRT light during this period, it must be pointed at a separate video source, and the system will not register a target for this cycle. It is also important to note that the IR preamplifier in the gun only triggers the sensor signal when it detects light characteristic of a CRT. It will not trigger the sensor signal if the gun is pointed at an ordinary light source.

After this period of blanking, the targeting controller sequentially displays white boxes for each of the three possible targets. If and when the Zapper detects light from the CRT beginning in one of these periods, the hit signal is sent to the Game Controller which then reads the current_target ID number, thereby registering a hit for that target.

4.0 Video Controller

For video, we use the MC6847 chip to output a 128x96 pixel, four-color image to the monitor. Target and background images are stored on a ROM. These images are then written to an SRAM based on directions from the game module. Writing to the SRAM is controlled by a set of major-minor FSMs, implemented in Verilog on a Flex10K70 FPGA (together with the gun and game modules).

4.1 Hardware Description

Hardware Components

The hardware components used in the video display circuit are:

3.579545 MHz Crystal Oscillator
Monitor
MC6847 Video Display Generator
Two 74LS04 Inverter Chips
22v10 PAL Chip
74LS123 Chip
Two 26LS32 Chips
Am28F512 ROM
MCM6264 SRAM
Assorted resistors, potentiometers, and capacitors

Hardware Circuits

In order to make the MC6847 compatible with the monitors in the lab (it was designed for use with standard TVs), we needed to run its outputs through several circuits: one to produce a clock signal, one to center the display, and one to convert the output of the MC6847 from analog signals into plain RGB signals.

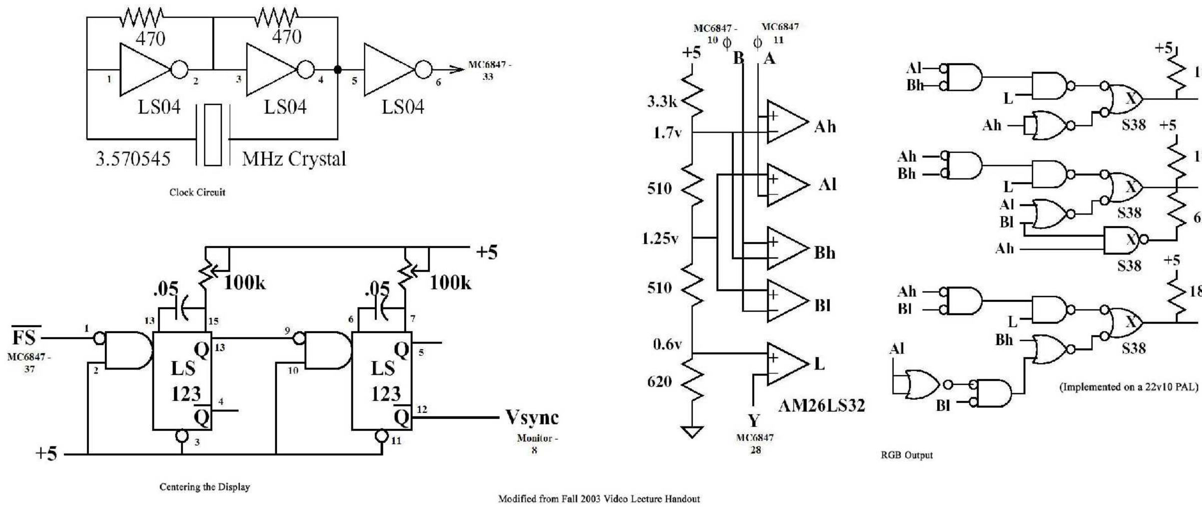


Figure 8. Video Circuits.

4.2 Module Design Descriptions

The Video Controller Module consisted of a top file and the following sub-modules: Bkgd_Image_Controller, Bkgd_Draw_FSM, Bkgd_Draw_FSM, Image_Draw_FSM, target_mode_controller, frame_timer, and bkgd_rom_addr_counter.

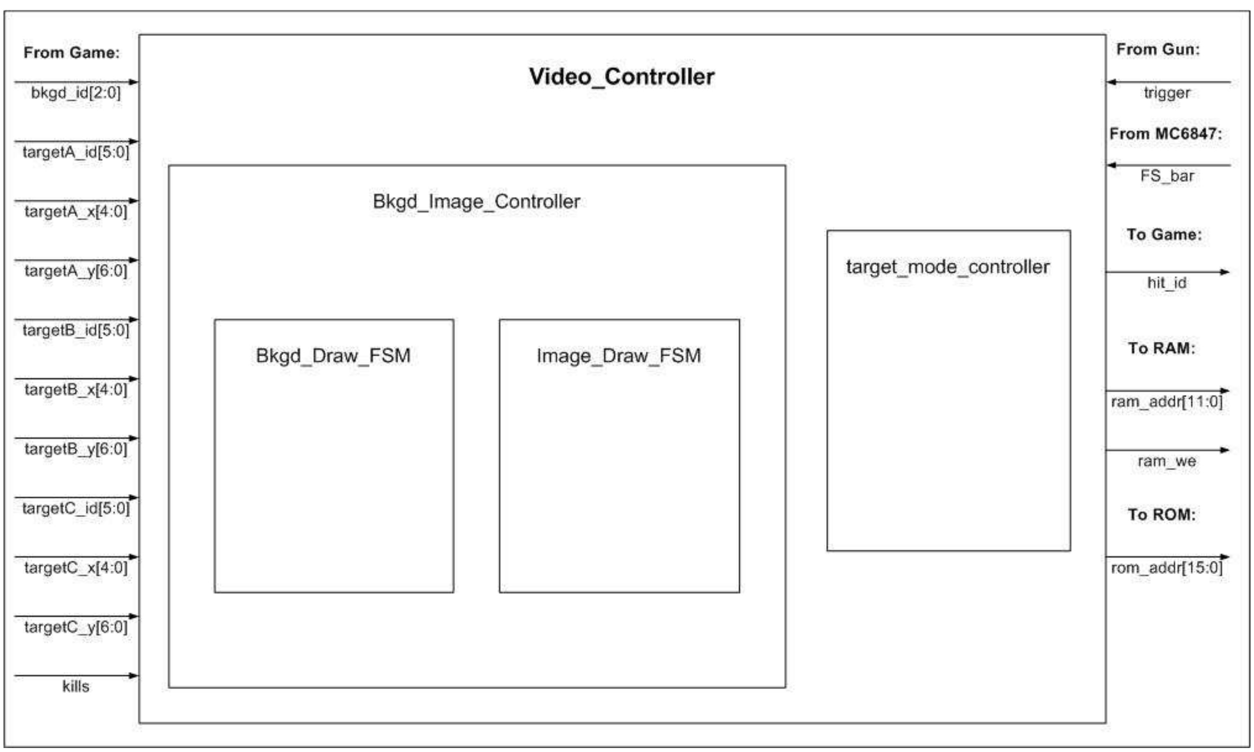


Figure 9. Video Module Block Diagram.

Video_Controller. The top file for the video control module, Video_Controller, uses the signal FS_bar, from the MC6847, to determine when it may write to RAM. When FS_bar is high, the chip is reading the data from the RAM, and Video_Controller tristates the RAM address bus and sets the RAM write enable (ram_we_bar) high. When FS_bar is low, it selects which of the address and signal sets is outputted. If it receives a trigger signal, it gives control to the target_output_controller module; otherwise, the Bkgd_Image_Controller signals are passed along.

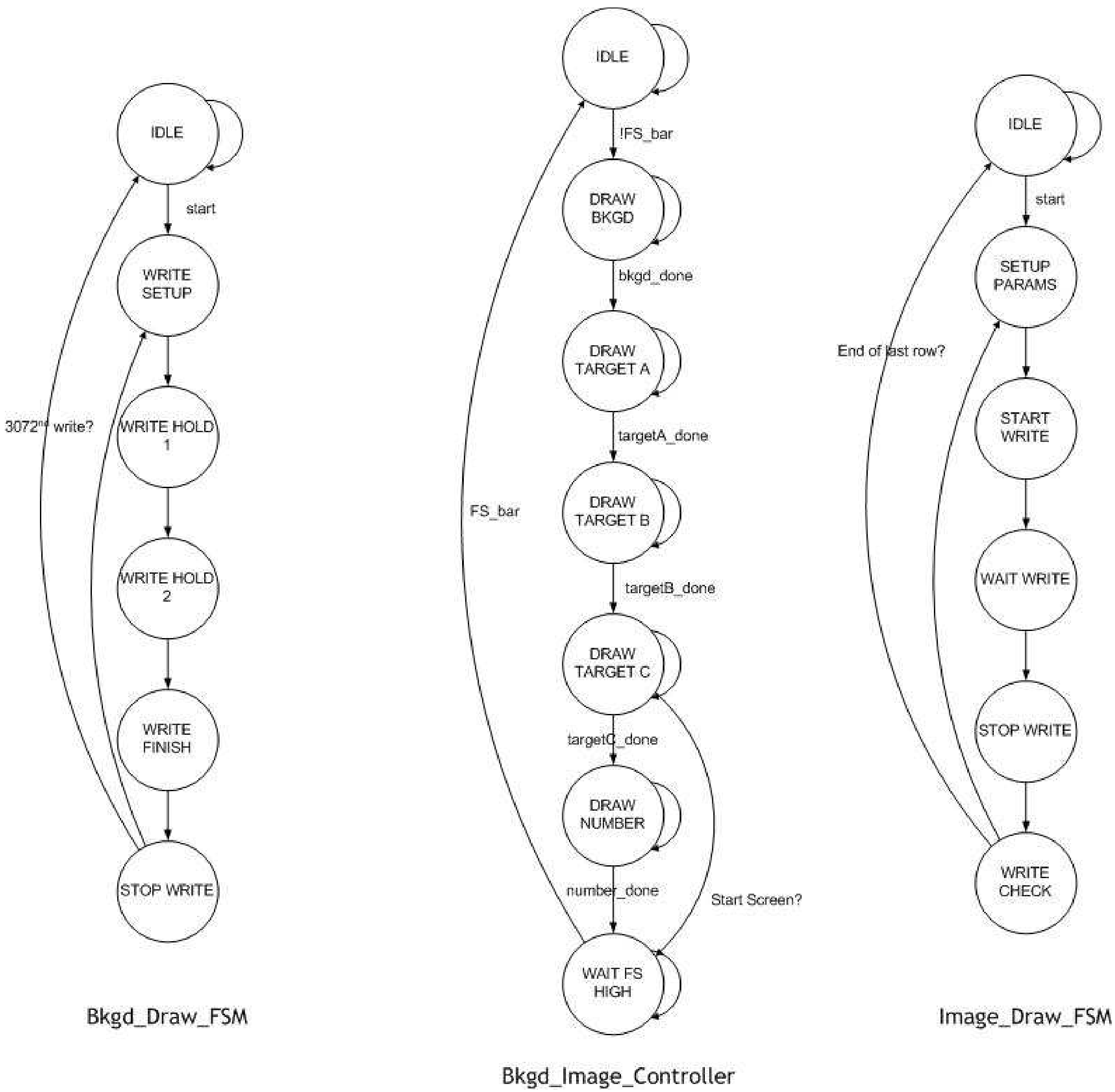


Figure 10. Major (center) and Minor FSMs

Bkgd_Image_Controller. The Major FSM for the picture output, this module begins writing to RAM when FS_bar goes low, cycling through FSMs for the background, each of the targets, and the hit count. When finished, it waits for the next low FS_bar to cycle through again. It passes the signals of each FSM up to the top module during its period of control.

Bkgd_Draw_FSM. Upon receiving a signal of “start” from the Bkgd_Image_Controller, this Minor FSM draws the background to the ROM, starting to read at a level-specific offset in the ROM, and looping through the RAM write cycle (shown in Figure 10; both Draw FSMs have the same timing for this write cycle) 3,072 times (width ÷ pixels per cell × length = 128/4*96).

Image_Draw_FSM. Upon receiving a signal of “start” from the Bkgd_Image_Controller, this Minor FSM takes inputs from the game module—the image id, the size, and the x and y coordinates—and calculates the address in RAM at which it will begin writing and the offset in ROM at which it will begin reading. It then loops through a row of the image in a similar fashion to the Bkgd_Draw_FSM, but when it gets to the end of the rom, it skips ahead in the RAM to the beginning location of the next row in the image.

Both Drawing FSMs give the RAM two clock cycles (on a 10MHz clock) to write; the RAM needs 100ns to write, so one clock cycle might barely be enough, but we err on the side of safety.

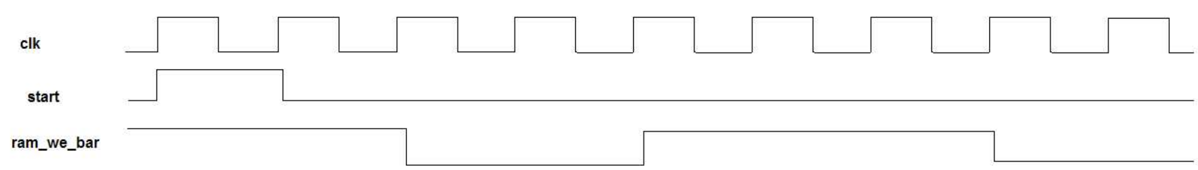


Figure 11. Draw FSMs Write Cycle Timing Diagram

bkgd_rom_addr_counter. This counter is used by the Bkgd_Draw_FSM to count from 0 to 3071 (the size of the background image).

size_counter. This counter is used by the Image_Draw_FSM to keep track of the row and line numbers.

5.0 The Game Controller

The gaming system is designed to output the location and image used for each target on the screen to the display system, as well as to generate important game information such as level and stage. To do this, the gaming system uses several components, including sample timers, a random number generator, an address selector, and several finite state machines, all of which can be seen in Figure 12. Since the FSMs are relatively complicated, the other components will be explained first.

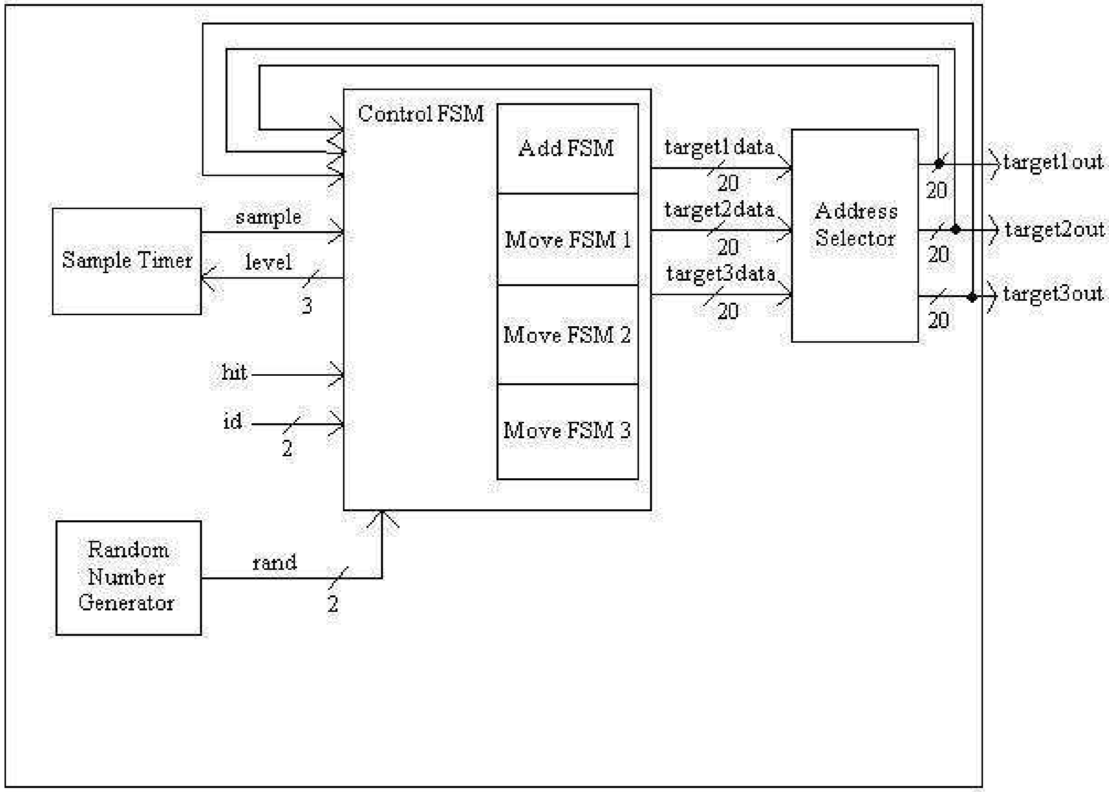


Figure 12. Game Controller Block Diagram.

5.1 Sample Timer

The sample timer uses a simple counter to make a pulse every time the targets on the screen should move to a new location on the display. Therefore, the actual speed of the targets on the screen is determined by the sample pulse rate. For the four different levels, there are four different numbers that the sample timer module counts to, at which point it creates the pulse. Based on the 10 MHz clock rate of the system, the rates of the sample timer for levels one through four are set to 10, 15, 22, and 35 pulses per second.

5.2 Random Number Generator

The random number generator creates a two-bit random number, which determine both the initial position of a target when it is created and the path it will travel across the screen. To create this random number, two linear feedback shift registers, or LFSRs, are used. Every clock cycle the bits in the flip flops shift over by one, with the new bit shifted in created from a function of bits already in the LFSR.

The LFSR is stuck at zero forever unless a seed is fed into it when the system is powered on. The same seed is always used since there is no way to calculate one using a system clock that can keep track of the date and time. To ensure that the numbers are random and will not cause the game to follow a single pattern every time, they are generated every clock cycle, making the number dependent on the number of clock cycles that have passed since the system has turned on.

The LFSRs used here are 20-bit registers. Ideally, there would be more bits, since the amount of time until the random number generator repeats itself is proportional to the number of bits in the LFSR. Still, since the random numbers are used fairly infrequently, the 20-bit LFSRs are sufficient to provide adequately random game play.

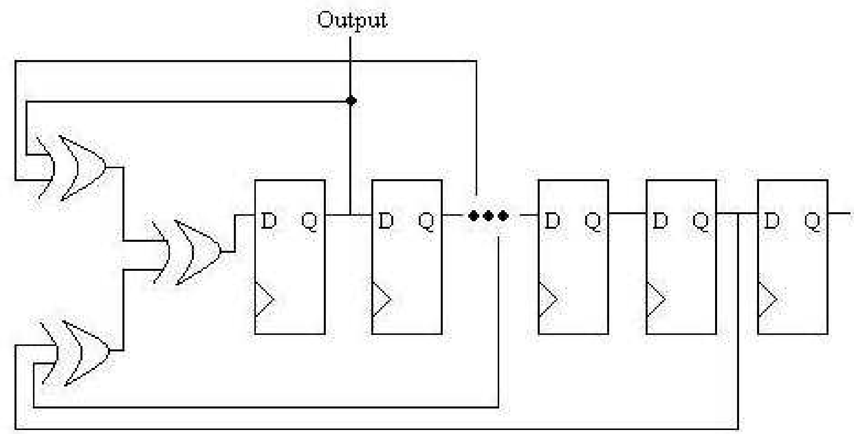


Figure 13. LFSR of arbitrary bit length.

5.3 Address Selector

The address selector is the component that keeps track of whether or not the hit signal from the gun goes high, indicating that a target has been hit. Based on the id of the target, which is given by the gun system, the address selector will erase the target from the display by changing the coordinates and image of the target such that the system will recognize that it should no longer be on the screen, as well as increase the number of targets hit by one. If no target was hit, i.e. the id is zero, then no change is made and the system continues normally. The address selector only recognizes the hit signal at its positive edge, guaranteeing that only one target can be hit at a time. The address selector is used because it greatly simplifies the overall gaming system, since it allows almost every other component to ignore the inputs of the gun system.

5.4 Control FSM

The control FSM is the major FSM of the system, handling the add and move FSMs, which respectively create targets on the screen and move them around. The FSM also generates important gaming variables such as the level and stage.

The control FSM is a Mealy machine with seven different states (Figure 14), as well as two extra wait states, which make the FSM go through two clock cycles before it transitions to a different state. Its initial state displays a single stationary target on the screen, and only when the target is hit does the FSM begin a transition.

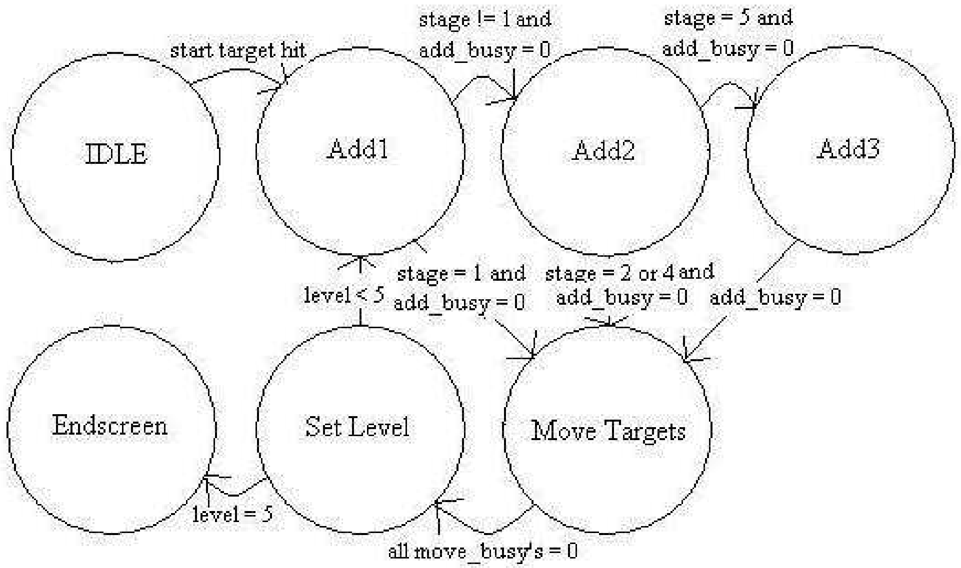


Figure 14. Control FSM Transition Diagram.

The next three states are each devoted to adding a single target to the screen. If only one target needs to be added, i.e. when stage equals one, then the FSM will only transition to the first add state, then go to the move state. If two need to be added, such as in stages two and four, it will transition to the first two add states, and then go to the move state, and if there need to be three targets, such as in stages three and five, all three add states will be used. Each add state starts the add FSM and waits until it is no longer busy to transition to the next state. If the randomly generated coordinates created are the same as the coordinates of a target already created, the add FSM is restarted so that different coordinates can be chosen.

In the move state, all the targets that have been created are controlled by their own move FSM, which are started when the control FSM transitions from its last add state. Each move FSM will continue working until either their target has been hit or it has reached the end of its path. When all three move FSMs are no longer busy, the control FSM transitions to the set level state, which determines what the game should do next. If the current stage is less than five, then it is increased by one and sent back to the add state. If the current stage is five and the level is less than four, then the stage is reset to zero and the level is incremented by one. If the stage is five and the level is four, then the control FSM transitions to the final end-screen state, where a blank screen is displayed with only the number of targets hit displayed, and the system must be reset to play again.

5.5 Add FSM

The Add FSM adds a single target to the screen, creating a random horizontal coordinate and path, as well as generating a preset vertical coordinate so the target will be near the bottom and setting the target to its largest size.

There are five states in the FSM (Figure 15). The FSM is always in its initial state until it receives a high start signal from the control FSM. In the gen x state, the x and y coordinates are set, one a random number and the other a constant. The FSM then transitions to a third state so that the random number generator can create a different random number for the path. In the gen path state, one of four paths is randomly chosen for the target, which is stored in the two lowest bits of the path signal. The highest bit determines whether the target travels left or right across the screen, so it is chosen based on whether the x coordinate is in the right half or the left half of the display respectively. Then, these signals are outputted from the FSM in the add and out states, in order to ensure that the data bus has valid data. The FSM then transitions back to the initial idle state.

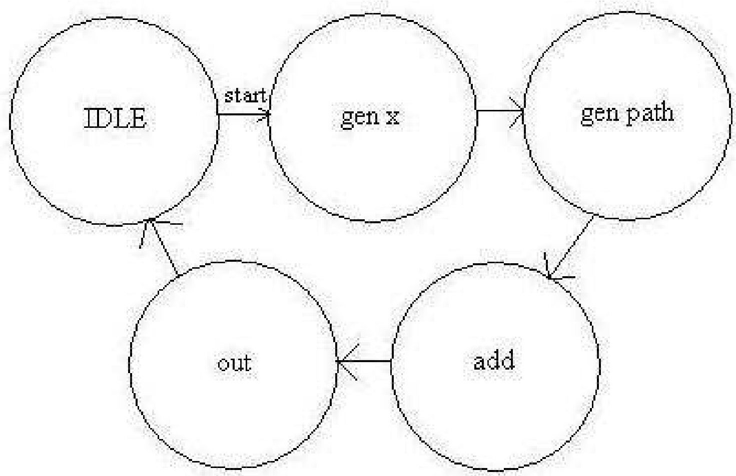


Figure 15. Add FSM Transition Diagram.

It should be noted that the targets are not all added at the exact same time in a given stage. However, the difference between the creations is only a few clock cycles, which is insignificant in real time.

5.6 Move FSM

The move FSM outputs a series of coordinates for its target as well as its size. These signals are based on the path that is chosen for a target in the add FSM as well as the coordinates that are fed into it by the control FSM.

There are six states in the FSM (Figure 16). The FSM begins in its initial state, until it is given a high start signal from the control FSM. Once this happens, it transitions to the wait sample state after going through a single waiting cycle, and then waits for a sample pulse from the sample timer. It then transitions to a get direction state, which determines which direction the target should be traveling in at this point in the path, based on a counter that is set to zero when the target is created. Then, the FSM transitions to the move state, where the x and y coordinates are changed based on the direction chosen, and the size is updated according to how far along the path the target has traveled. If the target has moved far enough, it is erased from the display and the FSM returns to the initial idle state. Otherwise, the FSM returns to the wait sample state once again, after going through another wait state to ensure that the correct signals are established. If at any point the target is hit by the gun, the move FSM stops and goes back to the idle state, setting its signals so that the target will not be displayed on the screen.

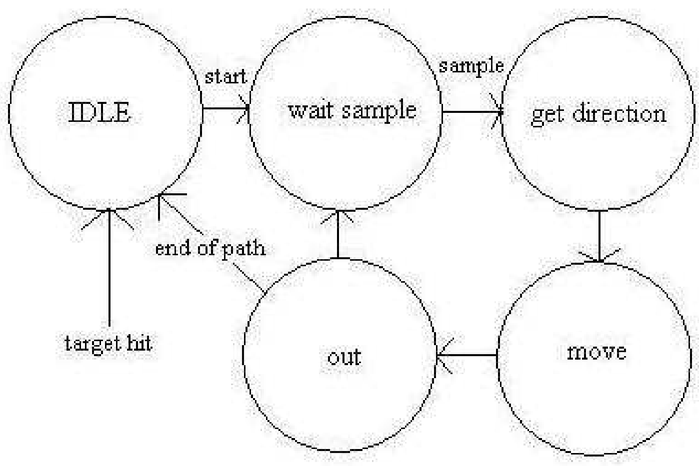


Figure 16. Move FSM Transition Diagram.

There are sixteen different directions that a target can move, each corresponding to a different number in the move FSM (Figure 17). These directions are used to create smooth arcs for the targets' paths. Since these paths are predetermined by the FSM, there is no way that any target can hit any edge of the display, so there are no boundary conditions to worry about.

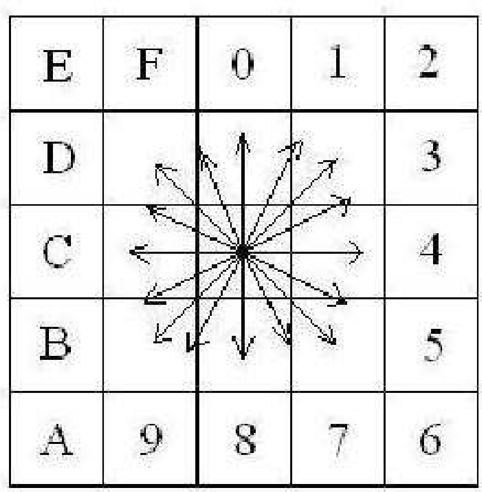


Figure 17. Target Movement.

6.0 Audio Extension

As an extra feature to enhance game-play in this project, we added a simple audio system to add sound effects to the Zapper. This was done by storing sound sampled at 11025 Hz on a separate

ROM and sending that data through the AD558 Digital to Audio Converter (DAC). This extra system is implemented on a second FPGA that parallels the main FPGA. It contained its own Gun Interface module and and Audio Controller wrapping a DAC FSM. When the trigger on the Zapper was pulled, a sound effect was played over the amplified speaker. The block diagram and control timing is shown in Figures 18 and 19.

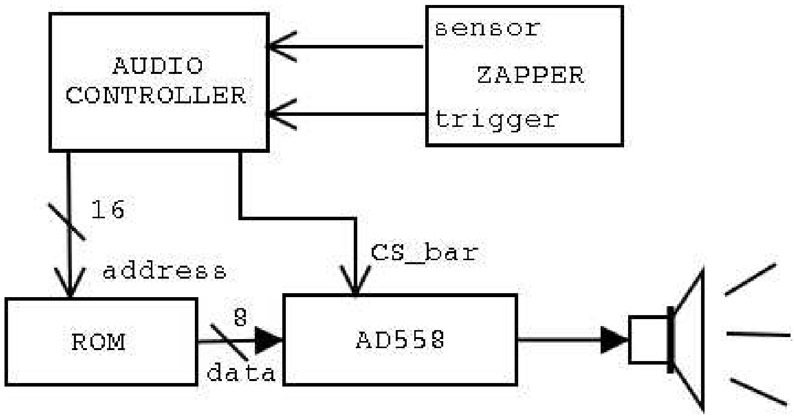


Figure 18. Audio Interface Extension. The trigger from the Zapper started the Audio Controller FSMs that played a sound effect from ROM through the AD558 DAC.

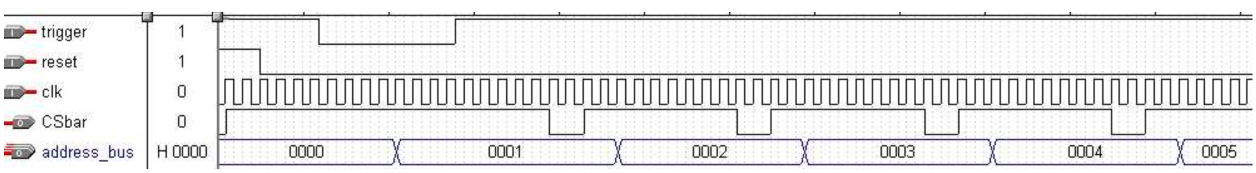


Figure 19. Audio Controller Timing Diagram. When the trigger is pressed the Audio Controller controls the address to the ROM as well as the CSbar signal going to the DAC.

7.0 Design and Debugging Issues

Difficulties with the MC6847

Our choice of the MC6847 as our video display generator was based on the reports of previous video targeting projects (Fall 2001 Duck Hunt, 1999 Wireless Marksmanship Trainer). Our project is different from these projects, however, in that we use *color* images. In retrospect, the decision to use the MC6847 limited some of our options (we might have found a chip more suited to our color needs). Unfortunately, having invested so much time into the circuitry needed to run the MC6847, we were left with little time to redesign the system after we realized its limitations. While the MC6847 is very useful for generating vertical and horizontal sync signals and controlling addressing to the RAM, it is a digital-to-analog converter. Our monitor can be fed digital inputs for Red, Green, and Blue. In fact, the circuitry we used converted the analog output of the MC6847 *back to digital*. Thus, the actual RGB output of the circuit is similar to what we might have fed directly to the monitor from memory, if we had encoded three-bit color, minus four options (though this would have involved many tricky timing issues with the sync signals, etc.). In our case, the mode we used only allowed us to select from four different colors—not a very attractive combination of colors, either. The mode we selected, Color Graphics Three, purports to allow for eight colors, but this promise requires that the user switch between two modes using a control signal. The actual data read by the MC6847 in this mode consists of 8-bit address locations on RAM, each representing a set of four pixels in a row. Thus, there was no space in which to encode the extra mode selector bit. Additionally, when we finally got the MC6847 working with the monitor, we found that it only wrote to the middle section of the screen, leaving a large border in one of two colors: green for one mode and white (called "buff" on the datasheet) in the other. For a project with a gun dependent upon white light for targeting information (both green and white register as "hits" with the gun), this situation was less than ideal.

Having resigned ourselves (due to time constraints) to four-bit color, we resolved to at least have the colors of our choice. By adding additional logic to the prescribed "RGB Output" circuit, we converted the colors of the mode we were using (CG3, CSS=0) as follows: Green (00) to Black (to make the border of the screen black), Yellow (01) to Green, Blue (10) stayed Blue, and Red (11) to White. This gave us the palette for traditional clay shooting and a screen compatible with the light gun.

Inter-kit signals and optimization

We began with the idea that the video, game, gun, and sound modules would be able to operate on separate kits. Initially, therefore, we were more concerned with accuracy than with efficiency. When we began to address system integration and interfaces, we realized that the game and video modules *had* to be on the same kit: they had far more communication channels than there were physical nodes on the kits. We put both modules on the kit, and realized we had another problem; when we ran wires to and from the gun module on another kit, the interaction of the kits produced many glitches on the monitor output. It turned out that the trigger signal was glitching badly in the transfer, in spite of several grounding wires between the kits. We then moved the gun module onto the same kit as the others. We got a basic version of our project working, and all was well.

Then, we decided to add the hit count to the screen. We began with the idea that we would add two digits, side by side. This involved adding a counter to the game and two instantiations of the Image_Draw_FSM to the Video module (as well as the images themselves, on the ROM). It would not fit. When we finally managed to fit it all on the Flex 10K70, we had turned the images into two-digit numbers (to reduce the number of additional FSMs to one), cut several identification bits by up to half of their original length, reduced the size of counters, cut the randomization factor in the game (for starting locations) by a factor of 2^29, and optimized all the FSMs (i.e., rather than having specified offsets for *all* the numbers, as we had been able to do for the limited number of scattered images, we calculated all of them off of one initial offset). Having to fight for 800, then 300, then those *last* 20 logic cells forced us to look critically at the efficiency of our code and drastically reduce excessive and inefficient methods. Occasionally, it forced us to sacrifice nice features, like the extensive randomization, but we found that the difference was not noticeable in practice.

8.0 Conclusions

Overall we feel we succeeded in most of the goals we set out to achieve. Had there been no time constraints we would have enjoyed implementing additional features such as wireless for the gun, extra sounds, a greater palette of colors, a more detailed game over screen, and more complicated game play. It would have helped to have had an FPGA that could hold more features.

What our final project does include is:

- Moving targets that appear at a random location and move away from the user on a predetermined path, shrinking as they disappear into the distance.
- Working gun interface that recognizes specific targets
- Four color video output
- Four five-stage levels, each with different backgrounds, targets, and speeds\
- Running score count
- Sound module to make realistic gun noise

```
/* Adds targets to the screen by generating initial x and y values
   while choosing a path for the target to follow.
*/
module addfsm(clk, reset, start, rand, busy, x, y, path);
	input clk, reset, start;
	input[1:0] rand;
	output busy;
	output[6:0] x, y;
	output[2:0] path;
	reg busy, busy_int;
	reg[6:0] x, y, x_int, y_int;
	reg[2:0] path, path_int, state, next;

	parameter IDLE = 0;
	parameter gen_x = 1;
	parameter gen_path = 2;
	parameter add = 3;
	parameter out = 4;

	parameter bottom = 57;
	parameter middle = 63;

	always @ (posedge clk) begin
		if (reset) state <= IDLE;
		else state <= next;
		x <= x_int;
		y <= y_int;
		path <= path_int;
		busy <= busy_int;
	end

	always @ (start or reset or state or next or rand or busy
		  or x or y or path)
		case(state)
		IDLE:		if (start) begin
				next = gen_x;
				busy_int = 1;
				y_int = bottom;
				end
				else begin
				next = IDLE;
				x_int = x;
				y_int = y;
				path_int = path;
				busy_int = 0;
				end
		gen_x:		begin
				next = gen_path;
				busy_int = 1;
				x_int = (rand * 25) + 15;
				y_int = bottom;
				end
		gen_path:		begin
				busy_int = 1;
				x_int = x;
				y_int = y;
				next = add;
				path_int[1:0] = rand[1:0];
				if (x > middle) path_int[2] = 1;
				else path_int[2] = 0;
				end
		add:		begin
				next = out;
				busy_int = 1;
				x_int = x;
				y_int = y;
				path_int = path;
				end
		out:		begin
				next = IDLE;
				busy_int = 0;
				x_int = x;
				y_int = y;
				path_int = path;
				end
		default:		begin
				next = IDLE;
				busy_int = 0;
				x_int = 0;
				y_int = 0;
				path_int = 0;
				end
		endcase
endmodule
```

```
/************************************
 Filename: addr_counter.v
 Author: Dave Kloster
 Custom counter used to cycle through
 the address bus of the Video RAM.
 ************************************/

module addr_counter(clk, reset, count, address, full);

   input clk, reset;
   input count;

   output full;
   reg    full;

   output [11:0] address;
   reg [11:0]   address;

   always @ (posedge clk or posedge reset) begin
      if (reset) begin
         address <= 0;
         full <= 0;
      end
      else if (count) begin
         address <= address + 1;
         if (address == 12'hC00) begin
         //if (address == 12'd50) begin  //TESTING VALUE
            full <= 1;
            address <= 0;
         end
         else full <= 0;
      end
      else address <= 0;
   end // always @ (posedge clk or posedge reset)
endmodule // addr_counter

/* This module decides if a target has been hit, and if it
   has, then changes its input so it will be erased from the
   display, and then adds one to the kill count.  Otherwise,
   no change is made to the input.
*/
module address_selector(clk, reset,
                       x1, y1, image1, size1,
                       x2, y2, image2, size2,
                       x3, y3, image3, size3,
                       x1_f, y1_f, image1_f, size1_f,
                       x2_f, y2_f, image2_f, size2_f,
                       x3_f, y3_f, image3_f, size3_f,
                       hit, id, level, kills);
input clk, reset, hit;
input [1:0] id;
input[2:0] image1, image2, image3, size1, size2, size3, level;
input[6:0] x1, x2, x3, y1, y2, y3;
output[2:0] image1_f, image2_f, image3_f, size1_f, size2_f, size3_f;
output[5:0] kills;
output[6:0] x1_f, x2_f, x3_f, y1_f, y2_f, y3_f;
reg[2:0] image1_f, image2_f, image3_f,
         size1_f, size2_f, size3_f,
         image1_int, image2_int, image3_int,
         size1_int, size2_int, size3_int;
reg[5:0] kills, kills_int;
reg[6:0] x1_f, x2_f, x3_f, y1_f, y2_f, y3_f,
        x1_int, x2_int, x3_int, y1_int, y2_int, y3_int;

always @ (posedge clk)
if (reset) begin
        x1_f <= 0;
        y1_f <= 0;
        image1_f <= 0;
        size1_f <= 7;
        x2_f <= 0;
        y2_f <= 0;
        image2_f <= 0;
        size2_f <= 7;
        x3_f <= 0;
        y3_f <= 0;
        image3_f <= 0;
        size3_f <= 7;
        kills <= 6'b111111;
end
else if (hit) begin
        x1_f <= x1_int;
        y1_f <= y1_int;
```

```
        image1_f <= image1_int;
        size1_f <= size1_int;
        x2_f <= x2_int;
        y2_f <= y2_int;
        image2_f <= image2_int;
        size2_f <= size2_int;
        x3_f <= x3_int;
        y3_f <= y3_int;
        image3_f <= image3_int;
        size3_f <= size3_int;
        kills <= kills_int;
end
else if (level == 6) begin
        x1_f <= x1;
        y1_f <= y1;
        image1_f <= image1;
        size1_f <= size1;
        x2_f <= x2;
        y2_f <= y2;
        image2_f <= image2;
        size2_f <= size2;
        x3_f <= x3;
        y3_f <= y3;
        image3_f <= image3;
        size3_f <= size3;
        kills <= 6'b111111;
end
else begin
        x1_f <= x1;
        y1_f <= y1;
        image1_f <= image1;
        size1_f <= size1;
        x2_f <= x2;
        y2_f <= y2;
        image2_f <= image2;
        size2_f <= size2;
        x3_f <= x3;
        y3_f <= y3;
        image3_f <= image3;
        size3_f <= size3;
        kills <= kills_int;
end

always @ (posedge hit)
if (id == 1 && image1 != 0) begin
        x1_int <= 0;
        y1_int <= 0;
        image1_int <= 0;
        size1_int <= 0;
        x2_int <= x2;
        y2_int <= y2;
        image2_int <= image2;
        size2_int <= size2;
        x3_int <= x3;
        y3_int <= y3;
        image3_int <= image3;
        size3_int <= size3;
        kills_int <= kills + 1;
end
else if (id == 2 && image2 != 0) begin
        x1_int <= x1;
        y1_int <= y1;
        image1_int <= image1;
        size1_int <= size1;
        x2_int <= 0;
        y2_int <= 0;
        image2_int <= 0;
        size2_int <= 0;
        x3_int <= x3;
        y3_int <= y3;
        image3_int <= image3;
        size3_int <= size3;
        kills_int <= kills + 1;
end
else if (id == 3 && image3 != 0) begin
        x1_int <= x1;
        y1_int <= y1;
        image1_int <= image1;
        size1_int <= size1;
        x2_int <= x2;
        y2_int <= y2;
        image2_int <= image2;
        size2_int <= size2;
        x3_int <= 0;
```

```
        y3_int <= 0;
        image3_int <= 0;
        size3_int <= 0;
        kills_int <= kills + 1;
end
else begin
        x1_int <= x1;
        y1_int <= y1;
        image1_int <= image1;
        size1_int <= size1;
        x2_int <= x2;
        y2_int <= y2;
        image2_int <= image2;
        size2_int <= size2;
        x3_int <= x3;
        y3_int <= y3;
        image3_int <= image3;
        size3_int <= size3;
        kills_int <= kills;
end

endmodule

/***************************************************
 * Background Drawing FSM
 * This minor FSM draws the background to the RAM.
 *
 * Author: Faye Kasemset
 **************************************************/

module Bkgd_Draw_FSM(clk, reset, start, done, bkgd_id,
                    bkgd_rom_addr, ram_addr, ram_we,
                    state);

   input clk, reset;
   input        start;
   input [2:0] bkgd_id;
   output [15:0] bkgd_rom_addr;
   output [11:0] ram_addr;
   output       ram_we;
   output       done;
   output [2:0] state;
   reg          done;
   reg          ram_we, ram_we_int;
   reg [2:0] bkdg_id;
   reg [2:0]   state, next;
   reg [15:0]  addr_offset, addr_offset_int;
   reg          addr_inc;
   wire [11:0]         addr;

   // Address Counter
   bkgd_rom_addr_counter addr_count1(.clk(clk),
                                    .reset(reset),
                                    .inc(addr_inc),
                                    .addr(addr));
   // Background ID parameters.
   parameter   LEVEL_START = 3'b110;
   parameter   BLANK = 3'b000;
   parameter   LEVEL1 = 3'b001;
   parameter   LEVEL2 = 3'b010;
   parameter   LEVEL3 = 3'b011;
   parameter   LEVEL4 = 3'b100;

   // ID addr offsets.
   parameter     LEVEL_START_OFFSET = 16'h2400;
   parameter     LEVEL1_OFFSET = 16'h0000;
   parameter     LEVEL2_OFFSET = 16'h0C00;
   parameter     LEVEL3_OFFSET = 16'h3000;
   parameter     LEVEL4_OFFSET = 16'h1800;

   // Wires out.
   assign ram_addr = addr;
   assign bkgd_rom_addr = addr + addr_offset;

   // State variables.
   parameter IDLE = 0;
   parameter WRITE_SETUP = 1;
   parameter WRITE_HOLD_1 = 2;
   parameter WRITE_HOLD_2 = 3;
   parameter WRITE_FINISH = 4;
   parameter STOP_WRITE = 5;

   always @ (posedge clk) begin
      if (!reset) begin
```

```
         state <= IDLE;
         addr_offset <= 16'b0;
         ram_we <= 0;
      end
      else begin
         state <= next;
         addr_offset <= addr_offset_int;
         ram_we <= ram_we_int;
      end
   end

   always @ (state or bkgd_id or addr) begin
      addr_offset_int = addr_offset;
      addr_inc = 0;
      ram_we_int = ram_we;
      done = 0;
      case (state)
        IDLE: begin
        ram_we_int = 0;
           if (start) next = WRITE_SETUP;
           else next = IDLE;
        end
        WRITE_SETUP: begin
        ram_we_int = 0;
           if (bkgd_id == LEVEL_START) addr_offset_int = LEVEL_START_OFFSET;
           if (bkgd_id == LEVEL1) addr_offset_int = LEVEL1_OFFSET;
           if (bkgd_id == LEVEL2) addr_offset_int = LEVEL2_OFFSET;
           if (bkgd_id == LEVEL3) addr_offset_int = LEVEL3_OFFSET;
           if (bkgd_id == LEVEL4) addr_offset_int = LEVEL4_OFFSET;
           next = WRITE_HOLD_1;
        end
        WRITE_HOLD_1: begin
           ram_we_int = 1;
           next = WRITE_HOLD_2;
        end
        WRITE_HOLD_2: begin
           ram_we_int = 1;
           next = STOP_WRITE;
        end
        STOP_WRITE: begin
           ram_we_int = 0;
           next = WRITE_FINISH;
        end
        WRITE_FINISH: begin
           ram_we_int = 0;
           if (addr == 3071) begin
              next = IDLE;
              done = 1;
           end
           else next = WRITE_SETUP;
           addr_inc = 1;
        end
        default: next = IDLE;
      endcase // case(state)
   end // always @ (state or bkgd_id or addr)
endmodule // Bkgd_Draw_FSM

 /*************************************************
 * Background and Image Controller.
 * FSM for drawing backgrounds and superimposing
 * images.  Contains separate FSMs for drawing
 * the background to the RAM, drawing the
 * three individual targets on top of the
 * background, and drawing the hit count.
 *
 * Author: Faye Kasemset
 *  *************************************************/

module Bkgd_Image_Controller(clk, reset, FS_bar, trigger,
                            kills, rom_addr, bkgd_id_ext,
                            targetA_id, targetB_id, targetC_id,
                            targetA_x, targetB_x, targetC_x,
                            targetA_y, targetB_y, targetC_y,
                            ram_addr, ram_we_bar, state,
                            bkgd_state, targetA_state,
                            targetB_state, targetC_state);



   input        clk, reset, FS_bar, trigger;
   input [5:0]         kills;
   input [2:0]         bkgd_id_ext;
   input [5:0]         targetA_id, targetB_id, targetC_id;
   input [6:0]         targetA_x, targetB_x, targetC_x;
```

```
input [6:0]        targetA_y, targetB_y, targetC_y;
output [15:0] rom_addr;
output [11:0] ram_addr;
output        ram_we_bar;
output [2:0]  state, bkgd_state, targetA_state,
             targetB_state, targetC_state;
reg          ram_we, ram_we_int;
assign       ram_we_bar = ~ram_we;
wire [2:0]   bkgd_id_ext;
wire [5:0]   kills;
wire         clk, reset, FS_bar, trigger;
reg [2:0]    fsm_sel, fsm_sel_int;
reg [2:0]    state, next;
reg          bkgd_start, targetA_start, targetB_start,
             targetC_start, number_start;
wire         bkgd_done, targetA_done, targetB_done,
             targetC_done, number_done;
wire [15:0]         bkgd_rom_addr, targetA_rom_addr,
             targetB_rom_addr, targetC_rom_addr,
             number_rom_addr;
wire [11:0]         bkgd_ram_addr, targetA_ram_addr,
             targetB_ram_addr, targetC_ram_addr,
             number_ram_addr;
wire         bkgd_ram_we, targetA_ram_we, targetB_ram_we,
             targetC_ram_we, number_ram_we;
wire [2:0]   bkgd_state;
wire [2:0]   targetA_state;
wire [2:0]   targetB_state;
wire [2:0]   targetC_state;
wire [2:0]   number_state;

// Minor FSMs:

// Background FSM (x1)
Bkgd_Draw_FSM bkdraw1(.clk(clk),
                    .reset(reset),
                    .start(bkgd_start),
                    .done(bkgd_done),
                    .bkgd_id(bkgd_id_ext),
                    .bkgd_rom_addr(bkgd_rom_addr),
                    .ram_addr(bkgd_ram_addr),
                    .ram_we(bkgd_ram_we),
                    .state(bkgd_state));
// Target FSMs (x3)
Image_Draw_FSM targetA1(.clk(clk),
                      .reset(reset),
                      .start(targetA_start),
                      .done(targetA_done),
                      .img_id({1'b0, targetA_id}),
                      .img_x(targetA_x),
                      .img_y(targetA_y),
                      .img_rom_addr(targetA_rom_addr),
                      .ram_addr(targetA_ram_addr),
                      .ram_we(targetA_ram_we),
                      .state(targetA_state));
Image_Draw_FSM targetB1(.clk(clk),
                      .reset(reset),
                      .start(targetB_start),
                      .done(targetB_done),
                      .img_id({1'b0, targetB_id}),
                      .img_x(targetB_x),
                      .img_y(targetB_y),
                      .img_rom_addr(targetB_rom_addr),
                      .ram_addr(targetB_ram_addr),
                      .ram_we(targetB_ram_we),
                      .state(targetB_state));
Image_Draw_FSM targetC1(.clk(clk),
                      .reset(reset),
                      .start(targetC_start),
                      .done(targetC_done),
                      .img_id({1'b0, targetC_id}),
                      .img_x(targetC_x),
                      .img_y(targetC_y),
                      .img_rom_addr(targetC_rom_addr),
                      .ram_addr(targetC_ram_addr),
                      .ram_we(targetC_ram_we),
                      .state(targetC_state));
// Hit Count FSM
Image_Draw_FSM num1(.clk(clk),
                  .reset(reset),
                  .start(number_start),
                  .done(number_done),
                  .img_id({1'b1, kills}),
                  .img_x(7'd28),
```

```
                   .img_y(7'd0),
                   .img_rom_addr(number_rom_addr),
                   .ram_addr(number_ram_addr),
                   .ram_we(number_ram_we),
                   .state(number_state));

// FSM_Sel IDs.
parameter    BKGD = 3'b000;
parameter    TARGET_A = 3'b001;
parameter    TARGET_B = 3'b010;
parameter    TARGET_C = 3'b011;
parameter     NUMBER = 3'b100;

assign       ram_addr = fsm_sel[2] ? number_ram_addr
             : (fsm_sel[1] ? (fsm_sel[0] ? targetC_ram_addr
                             : targetB_ram_addr)
                : (fsm_sel[0] ? targetA_ram_addr : bkgd_ram_addr));

assign       rom_addr = fsm_sel[2] ? number_rom_addr
             : (fsm_sel[1] ? (fsm_sel[0] ? targetC_rom_addr
                             : targetB_rom_addr)
                : (fsm_sel[0] ? targetA_rom_addr : bkgd_rom_addr));

// State variables.
parameter    IDLE = 0;
parameter    DRAW_BKGD = 1;
parameter    DRAW_TARGET_A = 2;
parameter    DRAW_TARGET_B = 3;
parameter    DRAW_TARGET_C = 4;
parameter    WAIT_FS_HIGH = 5;
parameter    DRAW_NUMBER = 6;

always @ (posedge clk) begin
   if (!reset) begin
      state <= IDLE;
      fsm_sel <= 3'b000;
      ram_we <= 0;
   end
   else begin
      state <= next;
      fsm_sel <= fsm_sel_int;
      ram_we <= ram_we_int;
   end
end

always @ (state or FS_bar or bkgd_done or targetA_done or
          targetB_done or targetC_done or bkgd_ram_we or
          targetA_ram_we or targetB_ram_we or targetC_ram_we) begin
   fsm_sel_int = fsm_sel;
   bkgd_start = 0;
   targetA_start = 0;
   targetB_start = 0;
   targetC_start = 0;
   number_start = 0;
   ram_we_int = 0;
    case (state)
      IDLE: begin
         if (!FS_bar) begin
            next = DRAW_BKGD;
            fsm_sel_int = BKGD;
            bkgd_start = 1;
            ram_we_int = bkgd_ram_we;
         end
         else next = IDLE;
      end
      DRAW_BKGD: begin
         ram_we_int = bkgd_ram_we;
         if (bkgd_done || FS_bar) begin
            next = DRAW_TARGET_A;
            fsm_sel_int = TARGET_A;
            targetA_start = 1;
            ram_we_int = targetA_ram_we;
         end
         else next = DRAW_BKGD;
      end
      DRAW_TARGET_A: begin
         ram_we_int = targetA_ram_we;
         if (targetA_done || FS_bar) begin
            next = DRAW_TARGET_B;
            fsm_sel_int = TARGET_B;
            targetB_start = 1;
            ram_we_int = targetB_ram_we;
         end
         else next = DRAW_TARGET_A;
```

```
         end
         DRAW_TARGET_B: begin
            ram_we_int = targetB_ram_we;
            if (targetB_done || FS_bar) begin
               next = DRAW_TARGET_C;
               fsm_sel_int = TARGET_C;
               targetC_start = 1;
               ram_we_int = targetC_ram_we;
            end
            else next = DRAW_TARGET_B;
         end
         DRAW_TARGET_C: begin
            ram_we_int = targetC_ram_we;
            if (targetC_done || FS_bar) begin
               if (bkgd_id_ext == 6) begin
                  next = WAIT_FS_HIGH;
                  ram_we_int = 0;
               end
               else begin
                  next = DRAW_NUMBER;
                  fsm_sel_int = NUMBER;
                  number_start = 1;
                  ram_we_int = number_ram_we;
               end // else: !if(bkgd_id_ext == 6)
            end
            else next = DRAW_TARGET_C;
         end
        DRAW_NUMBER: begin
           ram_we_int = number_ram_we;
           if (number_done || FS_bar) begin
              next = WAIT_FS_HIGH;
              ram_we_int = 0;
           end
           else next = DRAW_NUMBER;
        end
        WAIT_FS_HIGH: begin
           if (FS_bar) next = IDLE;
           else next = WAIT_FS_HIGH;
        end
        default: next = IDLE;
      endcase // case(state)
   end
endmodule // Bkgd_Image_Controller

 /*****************************************************
 * Background ROM Address Counter
 * This module keeps count for the Bkgd Draw FSM.
 * It counts from 0 to 3071 (There are 3072 locations
 * required to map the 128x96 screen) and then
 * resets itself.
 *
 * Author: Faye Kasemset
 *****************************************************/

module bkgd_rom_addr_counter(clk,
                             reset,
                             inc,
                             addr);
   input clk, reset, inc;
   output [11:0] addr;
   reg [11:0]      addr;
   always @ (posedge clk) begin
         // Reset takes precedence.
         if (!reset) addr <= 0;
         // Increment?
         else if (inc) begin
            // Already at 3071?  Set back to 0.
            if (addr == 3071) addr <= 0;
            // Otherwise, increment.
            else addr <= addr + 1;
         end
         else addr <= addr;
      end
endmodule // bkgd_rom_addr_counter

 /***********************************************
 Filename: blank_timer.v
 Author: Dave Kloster
 Sets the blanking time  for the shot/hit cycle
 for the gun interface of the NES Zapper.
 **********************************************/

module blank_timer(clk, reset, start, stop, time_up);
```

```
   //SET TO THE AMOUNT OF TIME TO WAIT.
   //VALUE DEPENDS ON DESIRED TIME AND
   //THE FREQUENCE OF THE CLOCK.
   parameter  TIMER_COUNT = 24'd400000;
   //USING 10MHz CLOCK, COUNTING TO 40 milli-SECONDs.

   input clk,reset,start,stop;

   output time_up;
   reg    time_up;

   reg [23:0] Q;
   reg        on;

   always @ (posedge clk or posedge reset) begin
      if (reset) begin
         Q <= 24'b0;
         time_up = 0;
         on = 0;
      end
      else if (stop) begin
         Q <= 24'b0;
         time_up = 0;
         on = 0;
      end
      else if (Q == TIMER_COUNT) begin
         time_up = 1;
         on = 0;
      end
      else if (on) begin
         Q <= Q + 1;
         on = 1;
      end
      else if (start) begin
         Q <= 24'b1;
         on = 1;
      end
   end // always @ (posedge clk or posedge reset)
endmodule // shot_timer

 /* This module acts as the Major FSM and also
   outputs valuable game information.
 */
module controlfsm(clk, reset, hit, id, sample, rand,
               x1_in, y1_in, x2_in, y2_in, x3_in, y3_in,
               x1, y1, image1, size1,
               x2, y2, image2, size2,
               x3, y3, image3, size3,
               level, image3_in);
input clk, reset, sample, hit;
input[1:0] id, rand;
input[2:0] image3_in;
input[6:0] x1_in, y1_in, x2_in, y2_in, x3_in, y3_in;
output[6:0] x1, y1, x2, y2, x3, y3;
output[2:0]            image1, image2, image3,
               size1, size2, size3, level;
reg     start_add, start_move_1, start_move_2, start_move_3,
       start_add_int, start_move_1_int, start_move_2_int, start_move_3_int;
reg[6:0] x1, y1, x2, y2, x3, y3,
        x1_int, y1_int, x2_int, y2_int, x3_int, y3_int;
reg [2:0] level, level_int, stage, stage_int,
         path_reg_1, path_reg_2, path_reg_3,
         path_1_int, path_2_int, path_3_int,
         image1, image2, image3,
         image1_int, image2_int, image3_int,
         size1, size2, size3;
reg[3:0] state, next, state_int, next_int;
wire busy_add, busy_move_1, busy_move_2, busy_move_3;
wire[2:0] path, size1_m, size2_m, size3_m;
wire[6:0] x_add, y_add, x1_in, y1_in, x2_in, y2_in, x3_in, y3_in,
         x1_out, y1_out, x2_out, y2_out, x3_out, y3_out;

addfsm add_target_1(.clk(clk), .reset(reset), .start(start_add), .rand(rand),
                   .busy(busy_add), .x(x_add), .y(y_add), .path(path));

movefsm move_target_1(.clk(clk), .reset(reset), .start(start_move_1),
                     .path(path_reg_1), .sample(sample), .busy(busy_move_1),
                     .x_in(x1_in), .y_in(y1_in), .x_out(x1_out),
                     .y_out(y1_out), .size(size1_m));
movefsm move_target_2(.clk(clk), .reset(reset), .start(start_move_2),
                     .path(path_reg_2), .sample(sample), .busy(busy_move_2),
                     .x_in(x2_in), .y_in(y2_in), .x_out(x2_out),
                     .y_out(y2_out), .size(size2_m));
movefsm move_target_3(.clk(clk), .reset(reset), .start(start_move_3),
```

```
                     .path(path_reg_3), .sample(sample), .busy(busy_move_3),
                     .x_in(x3_in), .y_in(y3_in), .x_out(x3_out),
                     .y_out(y3_out), .size(size3_m));

parameter IDLE = 0;
parameter add1 = 1;
parameter add2 = 2;
parameter add3 = 3;
parameter move_targets = 4;
parameter set_level = 5;
parameter waitcycle = 6;
parameter waitcycle2 = 7;
parameter endscreen = 8;

always @ (posedge clk)
        if (reset) begin
        x1 <= 0;
        y1 <= 0;
        x2 <= 0;
        y2 <= 0;
        x3 <= 0;
        y3 <= 0;
        level <= 0;
        stage <= 0;
        start_add <= 0;
        start_move_1 <= 0;
        start_move_2 <= 0;
        start_move_3 <= 0;
        path_reg_1 <= 0;
        path_reg_2 <= 0;
        path_reg_3 <= 0;
        size1 <= 7;
        size2 <= 7;
        size3 <= 7;
        state <= IDLE;
        end
        else begin
        x1 <= x1_int;
        y1 <= y1_int;
        x2 <= x2_int;
        y2 <= y2_int;
        x3 <= x3_int;
        y3 <= y3_int;
        level <= level_int;
        stage <= stage_int;
        start_add <= start_add_int;
        start_move_1 <= start_move_1_int;
        start_move_2 <= start_move_2_int;
        start_move_3 <= start_move_3_int;
        path_reg_1 <= path_1_int;
        path_reg_2 <= path_2_int;
        path_reg_3 <= path_3_int;
        image1 <= image1_int;
        image2 <= image2_int;
        image3 <= image3_int;
        if (state == IDLE) size3 <= 0;
        else size3 <= size3_m;
        size1 <= size1_m;
        size2 <= size2_m;
        state <= next;
        state_int <= next_int;
        end

always @ (state or next or sample or hit or id or level or stage
          or busy_add or busy_move_1 or busy_move_2 or busy_move_3
          or x1_out or y1_out or x2_out or y2_out or x3_out or y3_out
          or image3_in)
        case(state)
        IDLE:   if (hit && image3_in == 0) begin
                        start_add_int = 1;
                        start_move_1_int = 0;
                        start_move_2_int = 0;
                        start_move_3_int = 0;
                        next = waitcycle;
                        next_int = add1;
                        level_int = 1;
                        stage_int = 0;
                        image1_int = 1;
                        image2_int = 0;
                        image3_int = 0;
                        path_1_int = 0;
                        path_2_int = 0;
                        path_3_int = 0;
                        end
```

```
                else begin
                x1_int = 0;
                y1_int = 0;
                x2_int = 0;
                y2_int = 0;
                x3_int = 50;
                y3_int = 34;
                level_int = 6;
                stage_int = 0;
                image1_int = 0;
                image2_int = 0;
                image3_int = 6;
                start_add_int = 0;
                start_move_1_int = 0;
                start_move_2_int = 0;
                start_move_3_int = 0;
                path_1_int = 0;
                path_2_int = 0;
                path_3_int = 0;
                next_int = add1;
                next = IDLE;
                end
add1:           begin
                start_add_int = 0;
                stage_int = stage;
                level_int = level;
                start_move_1_int = 0;
                start_move_2_int = 0;
                start_move_3_int = 0;
                if (!busy_add && stage == 1) begin
                        x1_int = x_add;
                        y1_int = y_add;
                        path_1_int = path;
                        image1_int = level;
                        next = waitcycle;
                        next_int = move_targets;
                        start_move_1_int = 1;
                end
                else if (!busy_add) begin
                        x1_int = x_add;
                        y1_int = y_add;
                        path_1_int = path;
                        image1_int = level;
                        next = waitcycle;
                        next_int = add2;
                        start_add_int = 1;
                end
                else next = add1;
                end
add2:           begin
                start_add_int = 0;
                stage_int = stage;
                x1_int = x1;
                y1_int = y1;
                path_1_int = path_reg_1;
                level_int = level;
                start_move_1_int = 0;
                start_move_2_int = 0;
                start_move_3_int = 0;
                if (!busy_add && (x1 == x_add)) begin
                        next_int = add2;
                        next = waitcycle;
                        start_add_int = 1;
                end
                else if (!busy_add) begin
                        x2_int = x_add;
                        y2_int = y_add;
                        path_2_int = path;
                        image2_int = level;
                        next = waitcycle;
                        if ((stage == 2) || (stage == 4)) begin
                        next_int = move_targets;
                        start_move_1_int = 1;
                        start_move_2_int = 1;
                        end
                        else begin
                        next_int = add3;
                        start_add_int = 1;
                        end
                end
                else next = add2;
                end
add3:           begin
                stage_int = stage;
```

```
                start_add_int = 0;
                x1_int = x1;
                y1_int = y1;
                x2_int = x2;
                y2_int = y2;
                path_1_int = path_reg_1;
                path_2_int = path_reg_2;
                level_int = level;
                start_move_1_int = 0;
                start_move_2_int = 0;
                start_move_3_int = 0;
                if (!busy_add && (x1 == x_add || x2 == x_add)) begin
                        next_int = add3;
                        next = waitcycle;
                        start_add_int = 1;
                end
                else if (!busy_add) begin
                        x3_int = x_add;
                        y3_int = y_add;
                        path_3_int = path;
                        image3_int = level;
                        next = waitcycle;
                        next_int = move_targets;
                        start_move_1_int = 1;
                        start_move_2_int = 1;
                        start_move_3_int = 1;
                end
                else next = add3;
                end
move_targets:           begin
                stage_int = stage;
                level_int = level;
                start_add_int = 0;
                start_move_1_int = 0;
                start_move_2_int = 0;
                start_move_3_int = 0;
                x1_int = x1_out;
                y1_int = y1_out;
                x2_int = x2_out;
                y2_int = y2_out;
                x3_int = x3_out;
                y3_int = y3_out;
                image1_int = image1;
                image2_int = image2;
                image3_int = image3;
                path_1_int = path_reg_1;
                path_2_int = path_reg_2;
                path_3_int = path_reg_3;
                next = move_targets;
                if (!busy_move_1 && !busy_move_2 &&
                    !busy_move_3 && hit) begin
                        next = move_targets;
                        image1_int = 0;
                        image2_int = 0;
                        image3_int = 0;
                end
                else if (!busy_move_1 && !busy_move_2
                         && !busy_move_3) begin
                        next = waitcycle;
                        next_int = set_level;
                        image1_int = 0;
                        image2_int = 0;
                        image3_int = 0;
                end
                else if (!busy_move_1 && image1) begin
                        image1_int = 0;
                        next = move_targets;
                end
                else if (!busy_move_2 && image2) begin
                        image2_int = 0;
                        next = move_targets;
                end
                else if (!busy_move_3 && image3) begin
                        image3_int = 0;
                        next = move_targets;
                end
                else next = move_targets;
                end
set_level:              if (stage < 5) begin
                        next = waitcycle;
                        next_int = add1;
                        level_int = level;
                        stage_int = stage + 1;
                        start_add_int = 1;
```

```
                end
                else if (level < 4) begin
                        next = waitcycle;
                        next_int = add1;
                        stage_int = 1;
                        level_int = level + 1;
                        start_add_int = 1;
                end
                else begin
                        next = waitcycle;
                        x1_int = 0;
                        y1_int = 0;
                        x2_int = 0;
                        y2_int = 0;
                        x3_int = 0;
                        y3_int = 0;
                        level_int = 4;
                        stage_int = 0;
                        image1_int = 0;
                        image2_int = 0;
                        image3_int = 0;
                        start_add_int = 0;
                        start_move_1_int = 0;
                        start_move_2_int = 0;
                        start_move_3_int = 0;
                        next_int = endscreen;
                end
waitcycle:              begin
                                next = waitcycle2;
                                next_int = state_int;
                                level_int = level;
                                stage_int = stage;
                                image1_int = image1;
                                image2_int = image2;
                                image3_int = image3;
                                x1_int = x1;
                                y1_int = y1;
                                x2_int = x2;
                                y2_int = y2;
                                x3_int = x3;
                                y3_int = y3;
                                path_1_int = path_reg_1;
                                path_2_int = path_reg_2;
                                path_3_int = path_reg_3;
                                end
waitcycle2:             begin
                                next = state_int;
                                level_int = level;
                                stage_int = stage;
                                image1_int = image1;
                                image2_int = image2;
                                image3_int = image3;
                                x1_int = x1;
                                y1_int = y1;
                                x2_int = x2;
                                y2_int = y2;
                                x3_int = x3;
                                y3_int = y3;
                                path_1_int = path_reg_1;
                                path_2_int = path_reg_2;
                                path_3_int = path_reg_3;
                                end
endscreen:              begin
                                x1_int = 0;
                                y1_int = 0;
                                x2_int = 0;
                                y2_int = 0;
                                x3_int = 0;
                                y3_int = 0;
                                level_int = 4;
                                stage_int = 0;
                                image1_int = 0;
                                image2_int = 0;
                                image3_int = 0;
                                start_add_int = 0;
                                start_move_1_int = 0;
                                start_move_2_int = 0;
                                start_move_3_int = 0;
                                next = endscreen;
                                end
default:                begin
                next = IDLE;
                level_int = level;
                image1_int = image1;
```

```
                       image2_int = image2;
                       image3_int = image3;
                       end
        endcase
endmodule

 /* This module acts as the top level file for the
   entire gameplay system.
 */
module controller(clk, reset, hit, id,
                       x1, y1, image1, size1,
                       x2, y2, image2, size2,
                       x3, y3, image3, size3,
                       level, kills);
input clk, reset, hit;
input[1:0] id;
output[2:0] image1, image2, image3, size1, size2, size3, level;
output[5:0] kills;
output[6:0] x1, y1, x2, y2, x3, y3;
reg reset_sync;

wire[1:0] rand;
wire sample;
wire[6:0] x1_out, y1_out, x2_out, y2_out, x3_out, y3_out;
wire[2:0] image1_out, size1_out, image2_out, size2_out, image3_out, size3_out;

controlfsm controller(.clk(clk), .reset(reset_sync), .hit(hit), .id(id),
                     .sample(sample), .rand(rand),
                     .x1_in(x1), .y1_in(y1), .x2_in(x2), .y2_in(y2),
                     .x3_in(x3), .y3_in(y3),
                     .x1(x1_out), .y1(y1_out),
                     .image1(image1_out), .size1(size1_out),
                     .x2(x2_out), .y2(y2_out),
                     .image2(image2_out), .size2(size2_out),
                     .x3(x3_out), .y3(y3_out),
                     .image3(image3_out), .size3(size3_out),
                     .level(level), .image3_in(image3));
sample_timer sampler(.clk(clk), .reset(reset_sync), .level(level),
                    .sample(sample));
rndnum rng(.clk(clk), .reset(reset_sync), .rand_num(rand));
address_selector select(.clk(clk), .reset(reset_sync),
                       .x1(x1_out), .y1(y1_out),
                       .image1(image1_out), .size1(size1_out),
                       .x2(x2_out), .y2(y2_out),
                       .image2(image2_out), .size2(size2_out),
                       .x3(x3_out), .y3(y3_out),
                       .image3(image3_out), .size3(size3_out),
                       .x1_f(x1), .y1_f(y1),
                       .image1_f(image1), .size1_f(size1),
                       .x2_f(x2), .y2_f(y2),
                       .image2_f(image2), .size2_f(size2),
                       .x3_f(x3), .y3_f(y3),
                       .image3_f(image3), .size3_f(size3),
                       .hit(hit), .id(id), .level(level), .kills(kills));

always @ (posedge clk) reset_sync <= reset;

endmodule

 /*******************************************
 Filename: frame_timer.v
 Author: Dave Kloster
 Custom timer used to time the durations
 that targets appear in targeting mode.
 *******************************************/

module frame_timer(clk, reset, count, time_up);

   //SET TO THE AMOUNT OF TIME TO WAIT.
   //VALUE DEPENDS ON DESIRED TIME AND
   //THE FREQUENCE OF THE CLOCK.
   parameter  TIMER_COUNT = 20'd800000;
   //parameter  TIMER_COUNT = 24'd50;   //TESTING VALUE
   //USING 10MHz CLOCK, COUNTING TO .08 SECONDs.

   input      clk, reset, count;

   output     time_up;
   reg        time_up;

   reg [19:0] Q;

   always @ (posedge clk or posedge reset) begin
      if (reset) begin
```

```
         Q <= 20'b0;
         time_up = 0;
      end
      else if (count) begin
         Q <= Q + 1;
         if (Q == TIMER_COUNT) begin
            time_up = 1;
            Q <= 0;
         end
         else time_up = 0;
      end
      else begin
         Q <= 0;
         time_up = 0;
      end
   end // always @ (posedge clk or posedge reset)
endmodule // frame_timer

/**************************************
 Filename: gun_interface.v
 Author: Dave Kloster
 Provides accurate and synchronized
 trigger and hit signals interfaced
 from the NES Zapper.
 *************************************/

module gun_interface(clk, reset, sensor, trigger, shot, hit);

   input clk,reset,sensor,trigger;

   output shot,hit;
   reg    shot,hit;

   reg    sensor_sync,trigger_sync,sensor_temp,trigger_temp;

   //TIMER INSTALL
   reg       start,stop,time_up;
   shot_timer timer(
                   .clk(clk),
                   .reset(reset),
                   .start(start),
                   .stop(stop),
                   .time_up(time_up)
                   );

   //BLANK TIMER INSTALL
   reg       blank_start,blank_stop,blank_time_up;
   blank_timer timer2(
                     .clk(clk),
                     .reset(reset),
                     .start(blank_start),
                     .stop(blank_stop),
                     .time_up(blank_time_up)
                     );

   reg [1:0] state, next;

   //FSM PARAMETERS
   parameter IDLE = 0;
   parameter LOOK = 1;
   parameter WAIT = 2;
   parameter BLANK = 3;

   //CLOCK LOOP
   always @ (posedge clk or posedge reset) begin
      //synchronize signals
      sensor_temp <= sensor;
      sensor_sync <= sensor_temp;
      trigger_temp <= ~trigger;
      trigger_sync <= trigger_temp;

      if (reset) state <= IDLE;
      else state <= next;
   end // always @ (posedge clk or posedge reset)

   //FSM STATE IMPLEMENTATION
   always @ (state or trigger_sync or sensor_sync or time_up) begin

      //default values
      hit = 0;
      shot = 0;
      start = 0;
      blank_start = 0;
      blank_stop = 0;
```

```
      stop = 0;

      case (state)

        IDLE: begin
           stop = 1;
           blank_stop = 1;
           if (trigger_sync) begin
              shot = 1;
              next = BLANK;
           end
           else next = IDLE;
        end

        BLANK: begin
           shot = 1;
           start = 1;
           blank_start = 1;
           if (blank_time_up) next = LOOK;
           else next = BLANK;
        end

        LOOK: begin
           shot = 1;
           start = 1;
           blank_stop = 1;
           if (sensor_sync) begin
              hit = 1;
              next = WAIT;
           end
           else if (time_up) next = IDLE;
           else next = LOOK;
        end

        WAIT: begin
           shot = 1;
           hit = 1;
           if (time_up) next = IDLE;
           else next = WAIT;
        end

        default: next = IDLE;

      endcase // case(state)
   end // always @ (state or trigger_sync or sensor_sync or time_up)
endmodule // gun_interface

/****************************************
 * Image Drawing FSM
 * This module overlays the target images
 *  and hit counter onto the ROM.
 *
 * Author: Faye Kasemset
 ****************************************/

module Image_Draw_FSM(clk, reset, start, done,
                     img_id, img_x, img_y,
                     img_rom_addr, ram_addr,
                     ram_we, state);
   input clk, reset, start;
   input [6:0] img_id;
   input [6:0] img_x, img_y;
   output [15:0] img_rom_addr;
   output [11:0] ram_addr;
   output [2:0] state;
   output       ram_we;
   output done;
   reg   done;
   reg          ram_we, ram_we_int;
   reg [2:0]    state, next;
   reg [15:0]   addr_offset, addr_offset_int;
   reg [4:0]    length, length_int;
   reg [4:0]    width, width_int;
   reg          w_restart, w_inc, l_restart, l_inc;
   wire [4:0]   w_addr, l_addr;

   // Width and Length counters.
   size_counter width1(.clk(clk),
                      .reset(reset),
                      .restart(w_restart),
                      .inc(w_inc),
                      .addr(w_addr));
   size_counter length1(.clk(clk),
                       .reset(reset),
```

```
                    .restart(l_restart),
                    .inc(l_inc),
                    .addr(l_addr));

// Image ID parameters
parameter   BLANK = 7'b000111;
parameter   START_TARGET = 7'b110000;
parameter   FRISBEE28 = 7'b001000;
parameter   FRISBEE24 = 7'b001001;
parameter   FRISBEE20 = 7'b001010;
parameter   FRISBEE16 = 7'b001011;
parameter   FRISBEE12 = 7'b001100;
parameter   GHOST28 = 7'b010000;
parameter   GHOST24 = 7'b010001;
parameter   GHOST20 = 7'b010010;
parameter   GHOST16 = 7'b010011;
parameter   GHOST12 = 7'b010100;
parameter   FISH28 = 7'b011000;
parameter   FISH24 = 7'b011001;
parameter   FISH20 = 7'b011010;
parameter   FISH16 = 7'b011011;
parameter   FISH12 = 7'b011100;
parameter   BOTTLE28 = 7'b100000;
parameter   BOTTLE24 = 7'b100001;
parameter   BOTTLE20 = 7'b100010;
parameter   BOTTLE16 = 7'b100011;
parameter   BOTTLE12 = 7'b100100;

// ROM address offsets
parameter   START_TARGET_OFFSET = 16'hFAFC;
parameter   FRISBEE28_OFFSET = 16'hFDDC;
parameter   FRISBEE24_OFFSET = 16'hFEA0;
parameter   FRISBEE20_OFFSET = 16'hFF30;
parameter   FRISBEE16_OFFSET = 16'hFF94;
parameter   FRISBEE12_OFFSET = 16'hFFD4;
parameter   GHOST28_OFFSET = 16'hFBC0;
parameter   GHOST24_OFFSET = 16'hFC84;
parameter   GHOST20_OFFSET = 16'hFD14;
parameter   GHOST16_OFFSET = 16'hFD78;
parameter   GHOST12_OFFSET = 16'hFDB8;
parameter   FISH28_OFFSET = 16'hF6C4;
parameter   FISH24_OFFSET = 16'hF788;
parameter   FISH20_OFFSET = 16'hF818;
parameter   FISH16_OFFSET = 16'hF87C;
parameter   FISH12_OFFSET = 16'hF8BC;
parameter   BOTTLE28_OFFSET = 16'hF8E0;
parameter   BOTTLE24_OFFSET = 16'hF9A4;
parameter   BOTTLE20_OFFSET = 16'hFA34;
parameter   BOTTLE16_OFFSET = 16'hFA98;
parameter   BOTTLE12_OFFSET = 16'hFAD8;
parameter   ZERO_OFFSET = 16'hA000;

// State variables.
parameter   IDLE = 0;
parameter   SETUP_PARAMS = 1;
parameter   START_WRITE = 2;
parameter   WAIT_WRITE = 3;
parameter   WRITE_CHECK = 4;
parameter    STOP_WRITE = 5;

assign img_rom_addr = addr_offset + (width + 1)*l_addr + w_addr;
assign ram_addr = (32*(img_y + l_addr)) + (img_x + w_addr);

always @ (posedge clk) begin
   if (!reset) begin
      state <= IDLE;
      width <= 5'b0;
      length <= 5'b0;
      addr_offset <= 16'b0;
      ram_we <= 0;
   end
   else begin
      state <= next;
      width <= width_int;
      length <= length_int;
      addr_offset <= addr_offset_int;
      ram_we <= ram_we_int;
   end
end

always @ (state or width or length or l_addr or w_addr) begin
   ram_we_int = ram_we;
   addr_offset_int = addr_offset;
   width_int = width;
```

```
length_int = length;
w_restart = 0;
w_inc = 0;
l_restart = 0;
l_inc = 0;
done = 0;

case (state)
  IDLE: begin
     ram_we_int = 0;
     if (start) begin
        next = SETUP_PARAMS;
        l_restart = 1;
        w_restart = 1;
     end
     else next = IDLE;
  end
  SETUP_PARAMS: begin
     ram_we_int = 0;
     next = IDLE;
     if (img_id == BLANK) begin
        l_restart = 1;
        w_restart = 1;
        done = 1;
        next = IDLE;
     end
     else begin
        next = START_WRITE;
        width_int = 6 - img_id[2:0];
        length_int = 27 - (img_id[2:0]*4);
        if (img_id == START_TARGET) begin
          addr_offset_int = START_TARGET_OFFSET;
        end
        if (img_id == FRISBEE28) begin
          addr_offset_int = FRISBEE28_OFFSET;
        end
        if (img_id == FRISBEE24) begin
          addr_offset_int = FRISBEE24_OFFSET;
        end
        if (img_id == FRISBEE20) begin
          addr_offset_int = FRISBEE20_OFFSET;
        end
        if (img_id == FRISBEE16) begin
          addr_offset_int = FRISBEE16_OFFSET;
        end
        if (img_id == FRISBEE12) begin
          addr_offset_int = FRISBEE12_OFFSET;
        end
        if (img_id == GHOST28) begin
          addr_offset_int = GHOST28_OFFSET;
        end
        if (img_id == GHOST24) begin
          addr_offset_int = GHOST24_OFFSET;
        end
        if (img_id == GHOST20) begin
          addr_offset_int = GHOST20_OFFSET;
        end
        if (img_id == GHOST16) begin
          addr_offset_int = GHOST16_OFFSET;
        end
        if (img_id == GHOST12) begin
          addr_offset_int = GHOST12_OFFSET;
          next = START_WRITE;
        end
        if (img_id == FISH28) begin
          addr_offset_int = FISH28_OFFSET;
        end
        if (img_id == FISH24) begin
          addr_offset_int = FISH24_OFFSET;
        end
        if (img_id == FISH20) begin
          addr_offset_int = FISH20_OFFSET;
        end
        if (img_id == FISH16) begin
          addr_offset_int = FISH16_OFFSET;
        end
        if (img_id == FISH12) begin
          addr_offset_int = FISH12_OFFSET;
        end
        if (img_id == BOTTLE28) begin
          addr_offset_int = BOTTLE28_OFFSET;
        end
        if (img_id == BOTTLE24) begin
          addr_offset_int = BOTTLE24_OFFSET;
```

```
                end
                if (img_id == BOTTLE20) begin
                   addr_offset_int = BOTTLE20_OFFSET;
                end
                if (img_id == BOTTLE16) begin
                   addr_offset_int = BOTTLE16_OFFSET;
                end
                if (img_id == BOTTLE12) begin
                   addr_offset_int = BOTTLE12_OFFSET;
                end
                if (img_id[6] == 1'b1) begin
                   width_int = 3;
                   length_int = 11;
                   addr_offset_int = ZERO_OFFSET + (48 * img_id[5:0]);
                end
             end // else: !if(img_id == BLANK)
          end
          START_WRITE: begin
             ram_we_int = 1;
             next = WAIT_WRITE;
          end
          WAIT_WRITE: begin
             ram_we_int = 1;
             next = STOP_WRITE;
          end
          STOP_WRITE: begin
             ram_we_int = 0;
             next = WRITE_CHECK;
          end
          WRITE_CHECK: begin
             ram_we_int = 0;
             // Done with row?
             if (w_addr == width) begin
                // Increment l_addr.
                w_restart = 1;
                // Last row?
                if (l_addr == length) begin
                   l_restart = 1;
                   done = 1;
                   next = IDLE;
                end
                // Otherwise, go to next row.
                else begin
                   l_inc = 1;
                   next = SETUP_PARAMS;
                end
             end
             // Increment w_addr, continue.
             else begin
                w_inc = 1;
                next = SETUP_PARAMS;
             end
          end
        endcase // case(state)
   end
endmodule // Image_Draw_FSM

/* This module generates a random one or zero,
   based on an input seed and how many clock
   cycles have passed since power has turned on.
 */
module lfsr(clk, reset, seed, msb);
input clk, reset;
input [19:0] seed;
output msb;
reg msb;
reg [19:0] q;
wire [19:0] n_q;

assign n_q[18:0] = q[19:1];
assign n_q[19] = q[19] ^ q[6] ^ q[5] ^ q[1];

always @ (posedge clk) begin
if (reset) q <= seed;
else q <= n_q;
msb <= q[19];
end

endmodule

/* This module controls a single target, sending out a series
   of coordinates based on an input path, the input coordinates,
   and how long it has been since the target was created.
 */
```

```
module movefsm(clk, reset, start, path, sample, busy,
               x_in, y_in, x_out, y_out,
               size);
        input clk, reset, start, sample;
        input[2:0] path;
        input[6:0] x_in, y_in;
        output busy;
        output[6:0] x_out, y_out;
        output[2:0] size;
        reg busy, busy_int;
        reg[3:0] direction, direction_int;
        reg[6:0] x_out, y_out, x_int, y_int;
        reg[6:0] count, count_int;
        reg[2:0] size, size_int;
        reg[3:0] state, next, state_int, next_int;

        parameter IDLE = 0;
        parameter wait_sample = 1;
        parameter get_direction = 2;
        parameter move = 3;
        parameter out = 4;
        parameter waitcycle = 5;
        parameter waitcycle2 = 6;

        parameter zero_arc_right = 0;
        parameter one_arc_right = 1;
        parameter two_arc_right = 2;
        parameter three_arc_right = 3;
        parameter zero_arc_left = 4;
        parameter one_arc_left = 5;
        parameter two_arc_left = 6;
        parameter three_arc_left = 7;

        always @ (posedge clk) begin
                if (reset) begin
                state <= IDLE;
                state_int <= IDLE;
                count <= 0;
                size <= 7;
                end
                else begin
                state <= next;
                count <= count_int;
                size <= size_int;
                state_int <= next_int;
                end
                x_out <= x_int;
                y_out <= y_int;
                direction <= direction_int;
                busy <= busy_int;
        end

        always @ (state or next or start or busy or sample or path
                  or x_in or y_in or size or count)
                case(state)
                IDLE:           if (start) begin
                                busy_int = 1;
                                next = waitcycle;
                                next_int = wait_sample;
                                x_int = x_in;
                                y_int = y_in;
                                size_int = 0;
                                end
                                else begin
                                next = IDLE;
                                next_int = IDLE;
                                x_int = x_in;
                                y_int = y_in;
                                size_int = 7;
                                busy_int = 0;
                                direction_int = 0;
                                count_int = 0;
                                end
                wait_sample:            if (x_in == 0 && y_in == 0) begin
                                next = IDLE;
                                busy_int = 0;
                                x_int = x_in;
                                y_int = y_in;
                                size_int = 7;
                                end
                                else if (sample) begin
                                next = get_direction;
                                busy_int = 1;
                                count_int = count;
```

```
                x_int = x_in;
                y_int = y_in;
                size_int = size;
                end
                else begin
                next = wait_sample;
                busy_int = 1;
                count_int = count;
                x_int = x_in;
                y_int = y_in;
                size_int = size;
                end
get_direction:          if (x_in == 0 && y_in == 0) begin
                next = IDLE;
                busy_int = 0;
                x_int = x_in;
                y_int = y_in;
                size_int = 7;
                end
                else begin
                case(path)
                zero_arc_right:
                  if (count < 14) direction_int = 0;
                  else if (count > 13 && count < 24)
                    direction_int = 1;
                  else if (count > 23 && count < 28)
                    direction_int = 2;
                  else if (count > 27 && count < 30)
                    direction_int = 3;
                  else if (count > 29 && count < 31)
                    direction_int = 4;
                  else if (count > 30 && count < 33)
                    direction_int = 5;
                  else if (count > 32 && count < 36)
                    direction_int = 6;
                  else if (count > 35 && count < 42)
                    direction_int = 7;
                  else if (count > 41) direction_int = 8;
                  one_arc_right:
                    if (count < 17) direction_int = 0;
                    else if (count > 16 && count < 25)
                      direction_int = 1;
                    else if (count > 24 && count < 28)
                      direction_int = 2;
                    else if (count > 27 && count < 30)
                      direction_int = 3;
                    else if (count > 29 && count < 31)
                      direction_int = 5;
                    else if (count > 30 && count < 35)
                      direction_int = 6;
                    else if (count > 34 && count < 39)
                      direction_int = 7;
                    else if (count > 38) direction_int = 8;
                  two_arc_right:
                    if (count < 19) direction_int = 0;
                    else if (count > 18 && count < 25)
                      direction_int = 1;
                    else if (count > 24 && count < 28)
                      direction_int = 2;
                    else if (count > 27 && count < 30)
                      direction_int = 3;
                    else if (count > 29 && count < 32)
                      direction_int = 6;
                    else if (count > 31 && count < 36)
                      direction_int = 7;
                    else if (count > 35) direction_int = 8;
                  three_arc_right:
                    if (count < 22) direction_int = 0;
                    else if (count > 21 && count < 26)
                      direction_int = 1;
                    else if (count > 25 && count < 28)
                      direction_int = 2;
                    else if (count > 27 && count < 30)
                      direction_int = 3;
                    else if (count > 29 && count < 32)
                      direction_int = 6;
                    else if (count > 31 && count < 36)
                      direction_int = 7;
                    else if (count > 35) direction_int = 8;
                  zero_arc_left:
                    if (count < 14) direction_int = 0;
                    else if (count > 13 && count < 24)
                      direction_int = 15;
                    else if (count > 23 && count < 28)
```

```
                              direction_int = 14;
                            else if (count > 27 && count < 30)
                              direction_int = 13;
                            else if (count > 29 && count < 31)
                              direction_int = 12;
                            else if (count > 30 && count < 33)
                              direction_int = 11;
                            else if (count > 32 && count < 36)
                              direction_int = 10;
                            else if (count > 35 && count < 42)
                              direction_int = 9;
                            else if (count > 41) direction_int = 8;
                          one_arc_left:
                            if (count < 17) direction_int = 0;
                            else if (count > 16 && count < 25)
                              direction_int = 15;
                            else if (count > 24 && count < 29)
                              direction_int = 14;
                            else if (count > 27 && count < 30)
                              direction_int = 13;
                            else if (count > 29 && count < 31)
                              direction_int = 11;
                            else if (count > 30 && count < 35)
                              direction_int = 10;
                            else if (count > 34 && count < 39)
                              direction_int = 9;
                            else if (count > 38) direction_int = 8;
                          two_arc_left:
                            if (count < 19) direction_int = 0;
                            else if (count > 18 && count < 25)
                              direction_int = 15;
                            else if (count > 24 && count < 28)
                              direction_int = 14;
                            else if (count > 27 && count < 30)
                              direction_int = 13;
                            else if (count > 29 && count < 32)
                              direction_int = 10;
                            else if (count > 31 && count < 36)
                              direction_int = 9;
                            else if (count > 35) direction_int = 8;
                          three_arc_left:
                            if (count < 22) direction_int = 0;
                            else if (count > 21 && count < 26)
                              direction_int = 15;
                            else if (count > 25 && count < 28)
                              direction_int = 14;
                            else if (count > 27 && count < 30)
                              direction_int = 13;
                            else if (count > 29 && count < 32)
                              direction_int = 10;
                          else if (count > 31 && count < 36)
                            direction_int = 9;
                          else if (count > 35) direction_int = 8;
                          default direction_int = 0;
                        endcase
                        next = move;
                        busy_int = 1;
                        count_int = count;
                        x_int = x_in;
                        y_int = y_in;
                        size_int = size;
                        end
move:                   if (count > 53) begin
                        next = out;
                        busy_int = 1;
                        x_int = 0;
                        y_int = 0;
                        size_int = 7;
                        end
                        else begin
                        count_int = count + 1;
                        next = out;
                        busy_int = 1;
                        if ((direction == 1) || (direction == 7))
                          x_int = x_in + 1;
                        else if ((direction == 15) || (direction == 9))
                          x_int = x_in - 1;
                        else if ((direction > 1) && (direction < 7))
                          x_int = x_in + 2;
                        else if ((direction > 9) && (direction < 15))
                          x_int = x_in - 2;
                        else x_int = x_in;
                        if ((direction == 3) || (direction == 13))
                          y_int = y_in - 1;
```

```
                              else if ((direction == 5) || (direction == 11))
                                y_int = y_in + 1;
                              else if ((direction < 3) || (direction > 13))
                                y_int = y_in - 2;
                              else if ((direction > 5) && (direction < 11))
                                y_int = y_in + 2;
                              else y_int = y_in;
                              if (count < 9) size_int = 0;
                              else if (count > 8 && count < 18)
                                size_int = 1;
                              else if (count > 17 && count < 27)
                                size_int = 2;
                              else if (count > 26 && count < 36)
                                size_int = 3;
                              else if (count > 35 && count < 45)
                                size_int = 4;
                              else if (count > 44) size_int = 5;
                              end
               out:           if (x_in == 0 && y_in == 0) begin
                              next = IDLE;
                              busy_int = 0;
                              x_int = x_in;
                              y_int = y_in;
                              size_int = 7;
                              end
                              else begin
                              next = waitcycle2;
                              next_int = wait_sample;
                              busy_int = 1;
                              x_int = x_out;
                              y_int = y_out;
                              size_int = size;
                              count_int = count;
                              end
               waitcycle:             begin
                              next = state_int;
                              x_int = x_in;
                              y_int = y_in;
                              size_int = size;
                              busy_int = 1;
                              end
               waitcycle2:            begin
                              next = state_int;
                              x_int = x_out;
                              y_int = y_out;
                              busy_int = 1;
                              size_int = size;
                              count_int = count;
                              end
               default:               begin
                              next = IDLE;
                              busy_int = busy;
                              x_int = x_in;
                              y_int = y_in;
                              size_int = 7;
                              direction_int = direction;
                              end
               endcase
endmodule

/* This module creates a two-bit random number
   from two separate LFSRs.
 */
module rndnum(clk, reset, rand_num);
input clk, reset;
output [1:0] rand_num;

parameter seed1 = 20'b00010110111000111000;
parameter seed2 = 20'b01110011010111000011;

lfsr bitzero(.clk(clk), .reset(reset), .seed(seed1), .msb(rand_num[0]));
lfsr bitone(.clk(clk), .reset(reset), .seed(seed2), .msb(rand_num[1]));

endmodule

/* This module outputs a sample pulse at a given
   rate, which is determined by the input level.
 */
module sample_timer(clk, reset, level, sample);
input clk, reset;
input [2:0] level;
output sample;
reg sample;
reg [19:0] count, countlimit;
```

```
parameter sampleone = 999999; //10fps
parameter sampletwo = 666666; //15fps
parameter samplethree = 454545; //22fps
parameter samplefour = 285714; //35fps

//parameter testsample = 8; //used for simulation

always @ (posedge clk) begin
        if (reset) countlimit <= 0;
        else if (level == 1) countlimit <= sampleone;
        else if (level == 2) countlimit <= sampletwo;
        else if (level == 3) countlimit <= samplethree;
        else if (level == 4) countlimit <= samplefour;
        else countlimit <= 0;
        if (reset) begin
                count <= 0;
                sample <= 0;
        end
        else if (countlimit == 0) begin
                count <= 0;
                sample <= 0;
        end
        else if (countlimit == sampleone && level != 1) begin
                count <= 0;
                sample <= 0;
        end
        else if (countlimit == sampletwo && level != 2) begin
                count <= 0;
                sample <= 0;
        end
        else if (countlimit == samplethree && level != 3) begin
                count <= 0;
                sample <= 0;
        end
        else if (countlimit == samplefour && level != 4) begin
                count <= 0;
                sample <= 0;
        end
        else if (count == countlimit) begin
                count <= 0;
                sample <= 1;
        end
        else begin
                count <= count + 1;
                sample <= 0;
        end
end
endmodule

/************************************************
 Filename: shot_timer.v
 Author: Dave Kloster
 Sets the time values for the shot/hit cycle
 for the gun interface of the NES Zapper.
 ***********************************************/

module shot_timer(clk, reset, start, stop, time_up);

   //SET TO THE AMOUNT OF TIME TO WAIT.
   //VALUE DEPENDS ON DESIRED TIME AND
   //THE FREQUENCE OF THE CLOCK.
   parameter  TIMER_COUNT = 22'd3200000;
   //USING 10MHz CLOCK, COUNTING TO .32 SECONDs.

   input clk,reset,start,stop;

   output time_up;
   reg    time_up;

   reg [21:0] Q;
   reg        on;

   always @ (posedge clk or posedge reset) begin
      if (reset) begin
         Q <= 22'b0;
         time_up = 0;
         on = 0;
      end
      else if (stop) begin
         Q <= 22'b0;
         time_up = 0;
         on = 0;
      end
```

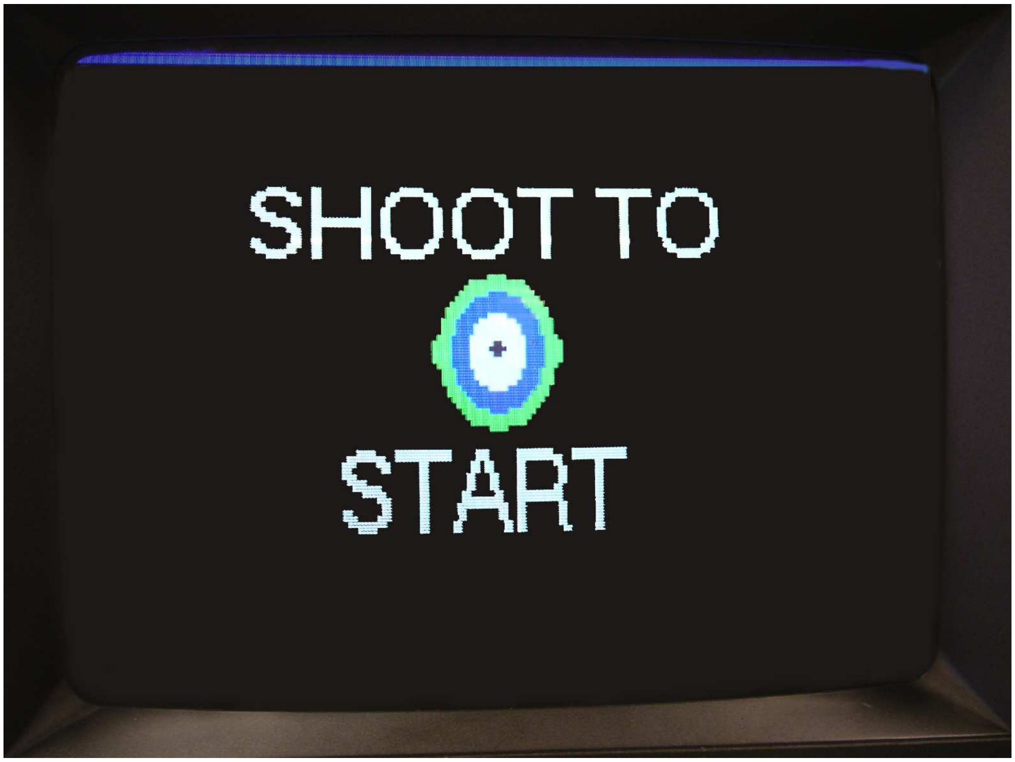
```
      else if (Q == TIMER_COUNT) begin
         time_up = 1;
         on = 0;
      end
      else if (on) begin
         Q <= Q + 1;
         on = 1;
      end
      else if (start) begin
         Q <= 22'b1;
         on = 1;
      end
   end // always @ (posedge clk or posedge reset)
endmodule // shot_timer

// This module keeps count for the Image Draw FSM.

// It counts from 0 to up to 64 (we assume no
// target will be larger than 64x64 pixels.

module size_counter(clk,
                   reset,
                   restart,
                   inc,
                   addr);

      input clk, reset, restart, inc;

      output [4:0] addr;
      reg [4:0]    addr;

      always @ (posedge clk) begin
         // Reset takes precedence.
         if (!reset) addr <= 0;
         // Restart?
         else if (restart) addr <= 0;
         // Increment?
         else if (inc) addr <= addr + 1;
         else addr <= addr;
      end

endmodule // bkgd_rom_addr_counter

/****************************************
 Filename: target_mode_controller.v
 Author: Dave Kloster
 Controls the display of white boxes to
 be read by the Light Gun when a shot
 has been fired.
 ****************************************/

module target_mode_controller (clk, reset,
                              targetA_size, targetA_x, targetA_y,
                              targetB_size, targetB_x, targetB_y,
                              targetC_size, targetC_x, targetC_y,
                              shot,
                              current_target,
                              RAM_address,
                              ROM_address
                              );

   input clk, reset;

   input [2:0] targetA_size, targetB_size, targetC_size;
   input [4:0] targetA_x, targetB_x, targetC_x;

   input [6:0]  targetA_y, targetB_y, targetC_y;

   input       shot;

   output [1:0] current_target;
   reg [1:0]   current_target;

   output [15:0] ROM_address;
   reg [15:0]   ROM_address, ROM_address_int;

   output [11:0] RAM_address;
   reg [11:0]   RAM_address, RAM_address_int;
   wire [4:0]      current_x;
   wire [6:0]      current_y;
   assign          current_x[4:0] = RAM_address[4:0];
   assign          current_y[6:0] = RAM_address[11:5];

   //ADDRESS LOCATIONS FOR ALL-BLACK
```

```
//OR ALL-WHITE DATA BITS.
parameter [15:0] black_address = 16'hFFFF;
parameter [15:0] white_address = 16'hFFFE;
//

//ADDR COUNTER INSTALL
reg [11:0]      addr_count;
addr_counter counter(
                    .clk(clk),
                    .reset(reset),
                    .count(addr_count),
                    .address(RAM_address_int)
                    );

//FRAME TIMER INSTALL
reg             frame_count;
reg             time_up;
frame_timer timer(
                 .clk(clk),
                 .reset(reset),
                 .count(frame_count),
                 .time_up(time_up)
                 );


//STATES
parameter       IDLE = 0;
parameter       BLANK = 1;
parameter       TARGET_A = 2;
parameter       TARGET_B = 3;
parameter       TARGET_C = 4;

reg [2:0]       state, next;

always @ (posedge clk or posedge reset) begin
   if (reset) state <= IDLE;
   else state <= next;

   ROM_address <= ROM_address_int;
   RAM_address <= RAM_address_int;

end

always @ (state or shot or time_up) begin

   ROM_address_int = black_address;
   addr_count = 1;
   frame_count = 1;
   current_target = 2'b0;

   case (state)

     IDLE: begin
        addr_count = 0;
        frame_count = 0;

        if (shot) next = BLANK;
        else next = IDLE;
     end


     BLANK: begin

        if (time_up) next = TARGET_A;
        else next = BLANK;
     end


     TARGET_A: begin
        current_target = 2'b01;
        if (current_x > (targetA_x - 5'd2)) begin
           if (current_x < (targetA_x - 5'b1) + {2'b0,~targetA_size}) begin
              if (current_y > (targetA_y - 7'b1)) begin
                 if (current_y < targetA_y + {2'b0,~targetA_size,2'b0}) begin
                    ROM_address_int = white_address;
                 end
              end
           end
        end

        if (time_up) next = TARGET_B;
        else next = TARGET_A;
     end // case: TARGET_A
```

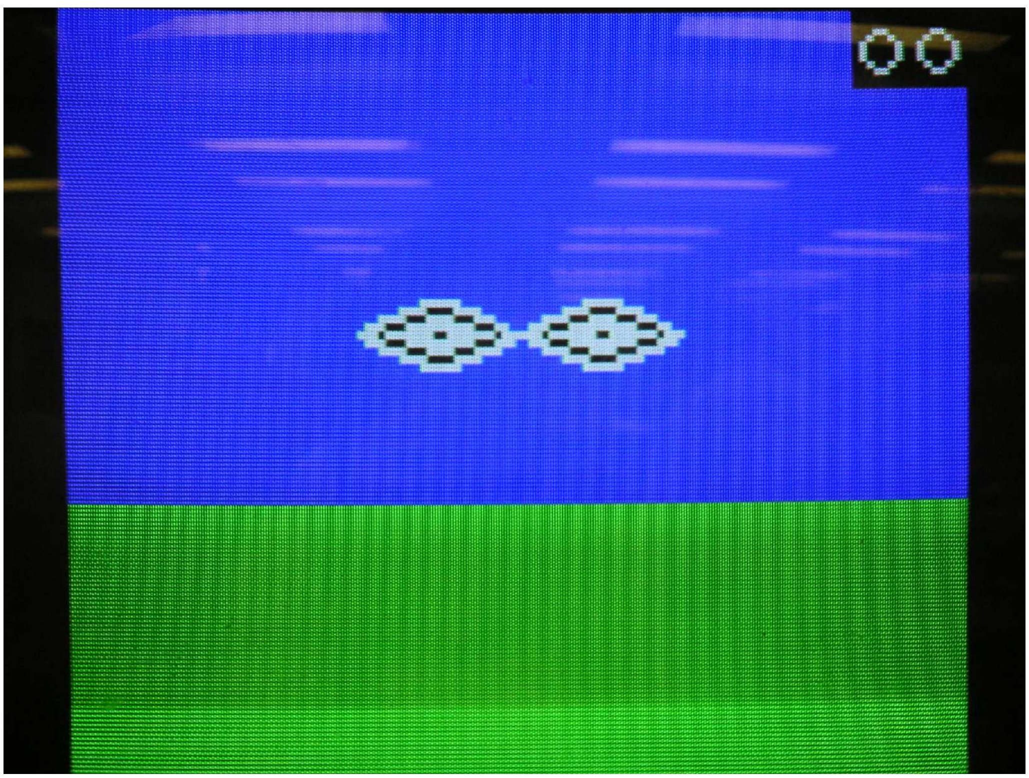
```
        TARGET_B: begin
           current_target = 2'b10;
           if (current_x > (targetB_x - 5'd2)) begin
              if (current_x < (targetB_x - 5'b1) + {2'b0,~targetB_size}) begin
                 if (current_y > (targetB_y - 7'b1)) begin
                    if (current_y < targetB_y + {2'b0,~targetB_size,2'b0}) begin
                       ROM_address_int = white_address;
                    end
                 end
              end
           end

           if (time_up) next = TARGET_C;
           else next = TARGET_B;
        end // case: TARGET_B


        TARGET_C: begin
           current_target = 2'b11;
           if (current_x > (targetC_x - 5'd2)) begin
              if (current_x < (targetC_x - 5'b1) + {2'b0,~targetC_size}) begin
                 if (current_y > (targetC_y - 7'b1)) begin
                    if (current_y < targetC_y + {2'b0,~targetC_size,2'b0}) begin
                       ROM_address_int = white_address;
                    end
                 end
              end
           end

           if (time_up) next = IDLE;
           else next = TARGET_C;
        end // case: TARGET_C


        default: next = IDLE;

      endcase // case(state)
   end // always @ (state or shot or time_up)
endmodule // target_mode_controller

module Top(clk, reset, hit, FS_bar, trigger_in, sensor, rom_addr, ram_addr, ram_we,
hit_id, bkgd_id);

   input clk, reset, FS_bar, trigger_in, sensor;
   output hit;
   output [11:0] ram_addr;
   output [15:0] rom_addr;
   output        ram_we;
   output [2:0] bkgd_id;
   output [1:0] hit_id;
   wire trigger;
   reg FS_bar_sync;
   wire [11:0] ram_addr;
   wire        ram_we;
   wire [15:0] rom_addr;
   wire [2:0]  bkgd_id;
   wire [5:0]  targetA_id, targetB_id, targetC_id;
   wire [6:0] targetA_xtop, targetB_x, targetC_x,
           targetA_y, targetB_y, targetC_y;
   wire [5:0] kills;
   // Game Module:
   controller game1(.clk(clk),
                    .reset(~reset),
                    .hit(hit),
                    .id(hit_id),
                    .x1(targetA_xtop),
                    .y1(targetA_y),
                    .image1(targetA_id[5:3]),
                    .size1(targetA_id[2:0]),
                    .x2(targetB_x),
                    .y2(targetB_y),
                    .image2(targetB_id[5:3]),
                    .size2(targetB_id[2:0]),
                    .x3(targetC_x),
                    .y3(targetC_y),
                    .image3(targetC_id[5:3]),
                    .size3(targetC_id[2:0]),
                    .level(bkgd_id),
                    .kills(kills));
   Video_Controller vc1(.clk(clk),
                        .reset(reset),
                        .ram_addr(ram_addr),
                        .ram_we(ram_we),
```

```
                       .rom_addr(rom_addr),
                       .FS_bar(FS_bar_sync),
                       .bkgd_id(bkgd_id),
                       .targetA_id(targetA_id),
                       .targetA_xvc(targetA_xtop[6:2]),
                       .targetA_y(targetA_y),
                       .targetB_id(targetB_id),
                       .targetB_x(targetB_x[6:2]),
                       .targetB_y(targetB_y),
                       .targetC_id(targetC_id),
                       .targetC_x(targetC_x[6:2]),
                       .targetC_y(targetC_y),
                       .trigger(trigger),
                       .hit_id(hit_id),
                       .kills(kills));
   gun_interface gun1(.clk(clk),
                     .reset(~reset),
                     .sensor(sensor),
                     .trigger(trigger_in),
                     .shot(trigger),
                     .hit(hit));
   // Synchronize input from MC6847
   always @ (posedge clk) FS_bar_sync <= FS_bar;
endmodule


/*****************************************************
 * Video Controller Top Module
 * Top level file for the video control module.
 * Controls output to MC6847 and switches between
 * targetting and drawing modes.
 *
 * Author: Faye Kasemset
 *****************************************************/

module Video_Controller(clk, reset, ram_addr, ram_we,
                       rom_addr, FS_bar, bkgd_id,
                       targetA_id, targetA_xvc, targetA_y,
                       targetB_id, targetB_x, targetB_y,
                       targetC_id, targetC_x, targetC_y,
                       trigger, hit_id, kills);
   input clk, reset;
   input [5:0] kills;
   input       FS_bar;
   input       trigger;
   input [2:0]         bkgd_id;
   input [5:0]         targetA_id, targetB_id, targetC_id;
   input [4:0]         targetA_xvc, targetB_x, targetC_x;
   input [6:0]         targetA_y, targetB_y, targetC_y;
   output [11:0] ram_addr;
   output      ram_we;
   output [15:0] rom_addr;
   output [1:0] hit_id;
   wire        target_ram_we;
   wire [11:0]         target_ram_addr;
   wire [15:0]         target_rom_addr;
   wire [1:0]  hit_id;
   wire [11:0]         bkgd_image_ram_addr;
   wire [15:0]         bkgd_image_rom_addr;
   wire        bkgd_image_ram_we;
   wire [2:0] bkgd_image_state;

   // Targetting Mode FSM:
   target_mode_controller target_control1(.clk(clk),
                                        .reset(~reset),
                                        .targetA_size(targetA_id[2:0]),
                                        .targetA_x(targetA_xvc),
                                        .targetA_y(targetA_y),
                                        .targetB_size(targetB_id[2:0]),
                                        .targetB_x(targetB_x),
                                        .targetB_y(targetB_y),
                                        .targetC_size(targetC_id[2:0]),
                                        .targetC_x(targetC_x),
                                        .targetC_y(targetC_y),
                                        .shot(trigger),
                                        .current_target(hit_id),
                                        .RAM_address(target_ram_addr),
                                        .ROM_address(target_rom_addr));

   // Regular Drawing Mode FSM:
   Bkgd_Image_Controller bkgd_img_cont1(.clk(clk),
                                      .reset(reset),
                                      .FS_bar(FS_bar),
                                      .trigger(trigger),
```

```
                                     .kills(kills),
                                     .rom_addr(bkgd_image_rom_addr),
                                     .bkgd_id_ext(bkgd_id),
                                     .targetA_id(targetA_id),
                                     .targetB_id(targetB_id),
                                     .targetC_id(targetC_id),
                                     .targetA_x({2'b00, targetA_xvc}),
                                     .targetB_x({2'b0, targetB_x}),
                                     .targetC_x({2'b0,targetC_x}),
                                     .targetA_y(targetA_y),
                                     .targetB_y(targetB_y),
                                     .targetC_y(targetC_y),
                                     .ram_addr(bkgd_image_ram_addr),
                                     .ram_we_bar(bkgd_image_ram_we),
                                     .state(bkgd_image_state));

   assign      ram_we = FS_bar ? 1 : (trigger ? 0 : bkgd_image_ram_we);
   assign      ram_addr = FS_bar ? 8'bZZ : (trigger ? target_ram_addr
                                          : bkgd_image_ram_addr);
   assign      rom_addr = trigger ? target_rom_addr : bkgd_image_rom_addr;
endmodule // Video_Controller
```

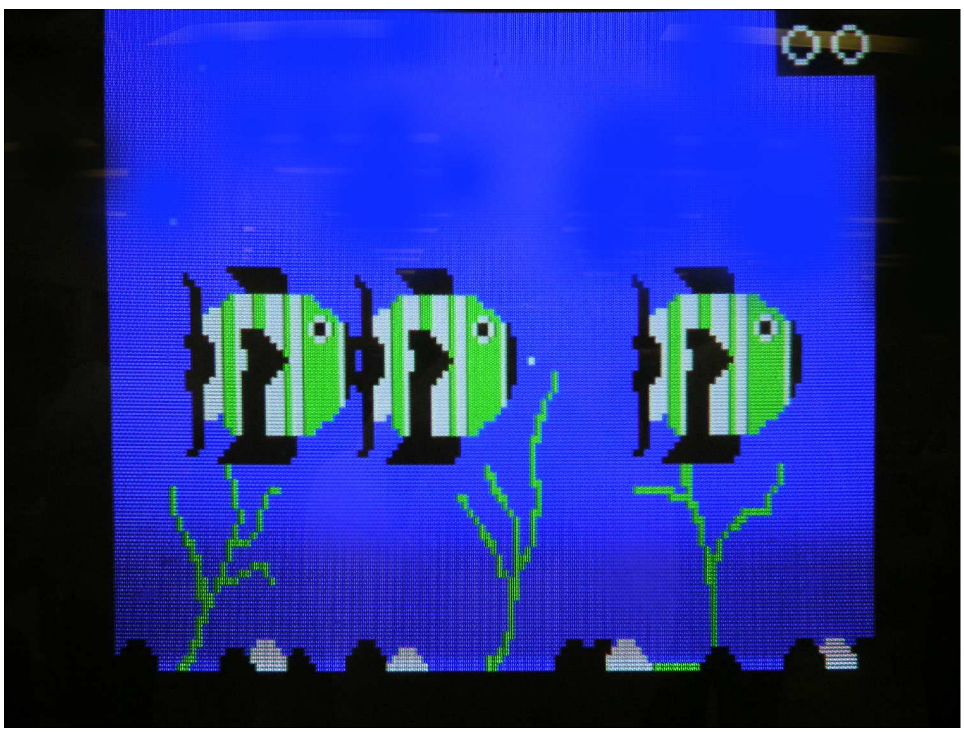


Start Screen



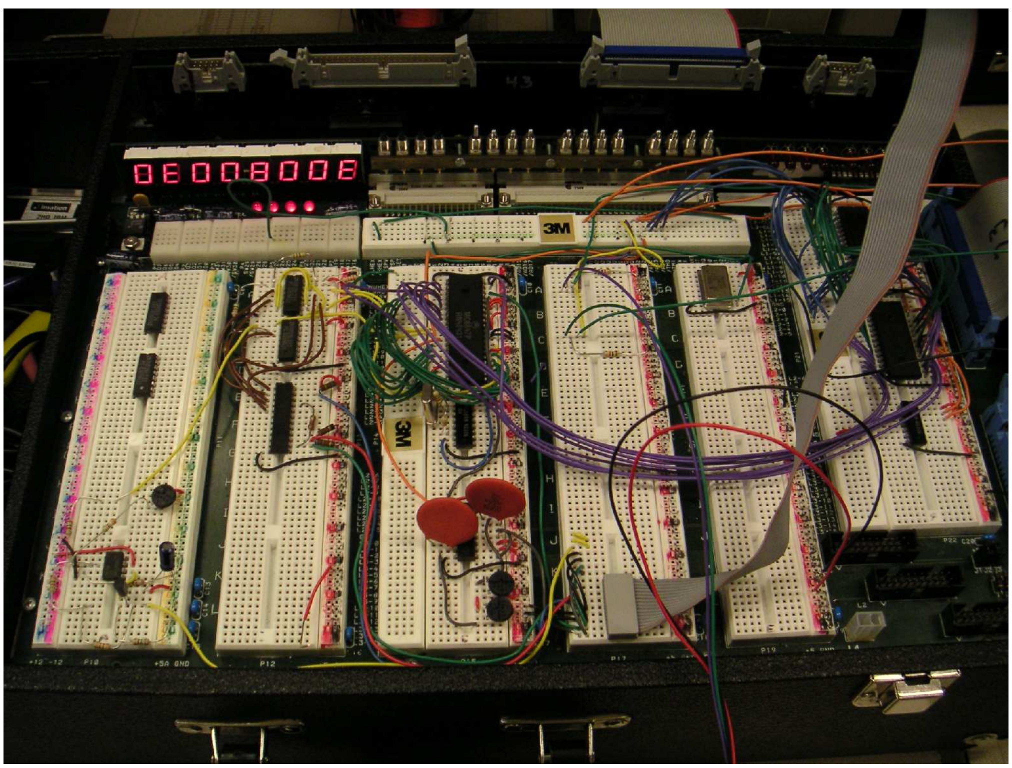
Level 1

Level 2

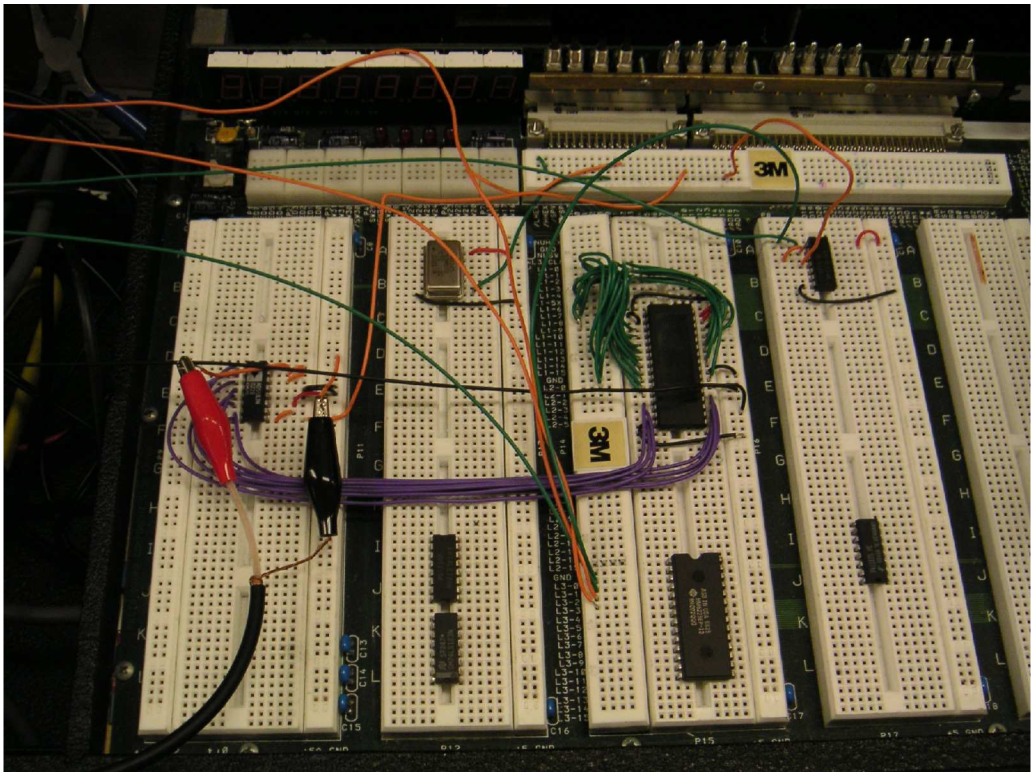


Level 3

Level 4



Video Circuit



Sound Circuit