

## VGA

# Introduction

Students will be introduced to the VGA interfaces and controllers in this recitation.

Understanding the interaction between the interfaces and controllers is key to understanding how to utilize different functional modules. Students will study the VGA controller and practice loading .mif files into their project directory. Students will alter the code so that the slide-switches on the FPGA will be used to control the memory location holding the information for an image to be displayed.

# Equipment

- Altera DE2-115 FPGA
- VGA Switch
- Monitor

# Lab Tasks

To receive credit for this lab, you must complete:

- ☐ Task 1: Understand the VGA architecture and be able to load different images
- ☐ Task 2: Clean up workstation

You must complete all parts of this lab to receive credit. A TA must sign-off on the completion of each task. Ensure that the TA marks the completion of the tasks in Sakai.

# Pre-Lab Instructions

There is no pre-lab.

# Lab Instructions

**NOTE: Items shown in red should be shown to the TA before continuing with the lab.**

## Understanding the VGA

In this part of the lab, you will re-use the QAR file from the last recitation to implement the VGA controller. This lab will help you to begin to get an understanding of how the VGA controller interfaces with the screen.

To start, open the “vga\_controller.v” module. In this module, there is a section where

instances of `img_data.v` and `img_index.v` are called and connected to the signals in the VGA controller. It's important to understand what they are doing, so after looking through the module, focus on this section and **write your thoughts about what you think this section of code does**. When you finish recording your thoughts, **call your TA over and check your observations**. Your TA will explain how this section provides the VGA controller with the information necessary to put an image on the screen.

The main idea behind how VGA works is that for each pixel on the screen, there is a 3-byte code that designates the values for red, blue, and green that the pixel will have. One byte for red, one for blue, one for green. The controller controls the image on the screen by updating one pixel at a time, doing all of the pixels in a given row on the screen, moving down to the next row, and similarly updating the color at each pixel. Once the controller gets to the last pixel on the screen, it moves back to the pixel at the beginning of the screen and starts the process over.

The color that a pixel takes on is the additive result of the red, blue, and green color values (e.g. white is `0xFFFFFF`, black is `0x000000`). In the controller, we have two modules, one that controls what pixel location we are at (`img_index.v`) and one that controls what the pixel value will be at that location (`img_data.v`). These modules interact with specified .mif files which hold the information used to display an image; this is useful because you can actually control the contents in a .mif file either by entering in the information manually, or by using the load/store instructions of the processor ISA you've implemented previously.

Do a full compilation if you haven't already and connect the VGA to the switch at your lab station. The image on the screen should be of the Altera DE2-115 logo. Open up the `img_data.v` and `img_index.v` modules and find the lines that designate the .mif files that contain the information. In the .mif file the `img_data` module calls, the mapping of a pixel address occurs (that is, for every byte in the .mif file, there is a 1-byte piece of information that will be used to locate the pixel color information in another .mif file). Notice how there are `0x4AFF` total memory locations; in decimal, this is 307,200. For a 640x480 sized screen, this means that each pixel is mapped on a 1:1 basis (do the math if this doesn't make sense at first). The `img_index` module maps to the .mif file that contains the pixel color info. Notice that in this file, there are only `0xFF` locations, each holding 3-bytes worth of information. These are the colors that the pixels will have.

After looking through these files, the manner in which the image on the screen is generated should start to make sense. **Talk to your TA in case you need a little more help to understand these concepts!**

Next, you will control the image being displayed on the screen by modifying the files provided for you. Using the `lab7_img.mif` and `lab7_img_index.mif` files, make the VGA display 2 different solid colors (one on the top half of the screen and one on the bottom half). To make the process of editing the contents of the .mif cells, go to Edit-->Fill Cells with 0's, Fill Cells with 1's, Custom Fill Cells... in order to edit cell contents.

**Show your TA when you finish this section.**

For the last VGA task, you will be rendering a square image over the two-colored background you have created, and allowing it to move in all 4 directions on the screen through button inputs. Buttons are high when not pressed. You can use as much behavioral verilog as needed to complete this. The following is an **example** of how you could do this, **not necessarily what you will do for your own work**.

First, you must choose a reference point on the square in order to keep track of its location (e.g., top left corner). Knowing this, create registers in behavioral verilog to store the x and y coordinates of this position on the square.

The next step to complete is movement. Create 4 input signals for each direction of movement. As skeleton is the top level module, you will have to add these inputs to skeleton.v as well (don't forget to add them to the instantiation of vga\_controller). Using an always block, update the x and y coordinate registers based on the input signals. Consider how frequently this always block should latch new values, and how this will affect the speed at which your square moves across the screen. A counter will likely be needed (look at the address generator for reference). Remember, you can use behavioral verilog such as "==" to make sure the always block only updates when the counter is at a specific value.

Finally, you will need to create a multiplexer that chooses between displaying the background image or the square for any given value of "ADDR". In order to easily do so, create a module that converts the linear pixel address into x and y coordinates. Hint: addressing begins in the top left corner of the screen and goes across then down. For example, address 0 is the top left pixel, and address 640 is directly below. Using different comparison symbols such as "<", as well as addition and subtraction, find a way to choose whether the background is displayed at a specific address given its x and y coordinates and the x and y coordinates of the square. **If you get stuck anywhere in this process, make sure to ask your TA for help. Understanding this process is very critical. Show your TA when you finish this section.**

## Clean Up Workstation

Clean up your workstation, making sure you put any broken pieces in the black "discard" bin. Put probes back on the wall, wires back in the wire bin, breadboards on top of the workstation, and all circuit pieces back in their respective bins.

**You will not be able to pass this lab if you do not clean up after yourself.**

## Grading

- Completing Lab Tasks: 100 points (pass/fail)
- **Due: Friday, Oct 20, 2023 by 11:59AM (Beijing time)**