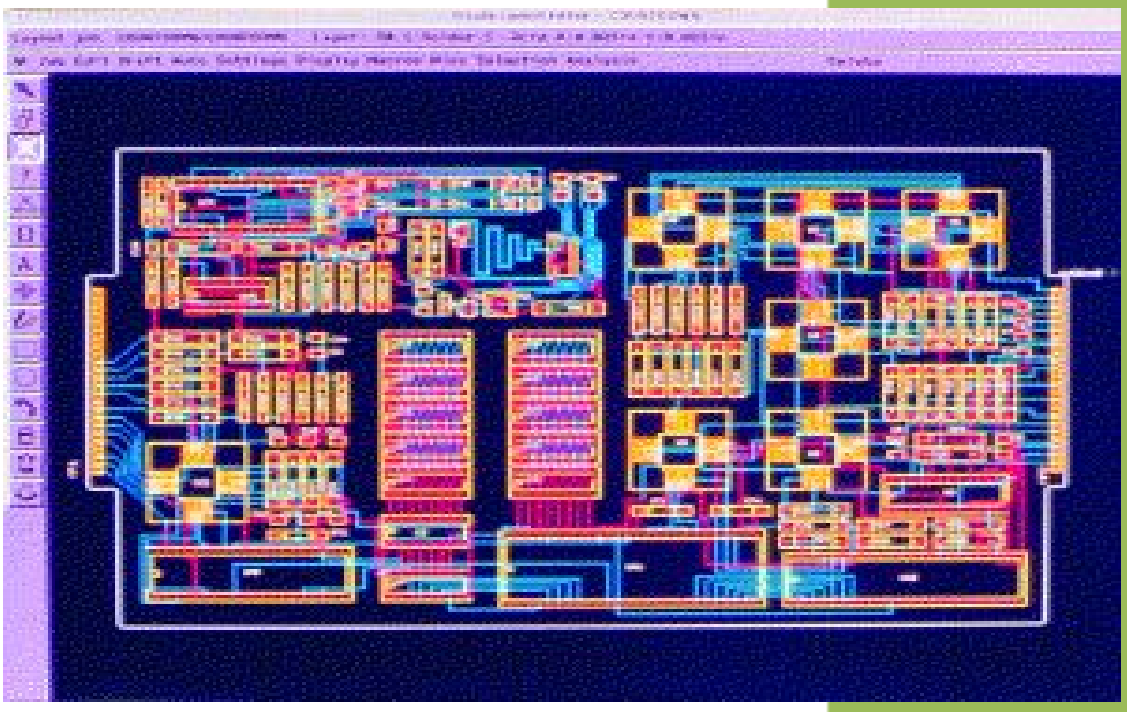
Computer Engineering Department
Faculty of Engineering
Cairo University

Spring 2017
CMP 305
VLSI

Camera Enhancement Module

2017



VLSI Semester Term Project
Phase One

VLSI Project

Computer Engineering Department

Objectives

- To better understand Digital Design Flow
- To be proficient at VHDL
- To create real world hardware applications
- To understand the mapping between Algorithm Specifications & Hardware Implementation
- To understand Design Trade-offs
- To learn how to optimize Hardware Designs

Introduction

In real world applications, camera modules ICs market has been gaining momentum in the past few years because of the increasing demand for consumer electronics devices such as smartphones, tablet PCs, digital cameras. The growth of this market was driven by the increasing trend of sharing images and videos using advanced media-sharing technologies which are the major aspect of social networking on a global basis within the smartphone and multimedia tablet ecosystem. Moreover, the growing market for advanced driver assistance systems (ADAS) in the automotive sector is boosting the demand for image sensors, and in turn, camera modules. The Total Camera Modules Market is Expected to Reach USD 36.95 Billion by 2020. [1]

In this project, you will experience the whole cycle of Design & Fabricating a system on chip, best described as in Figure 1 .

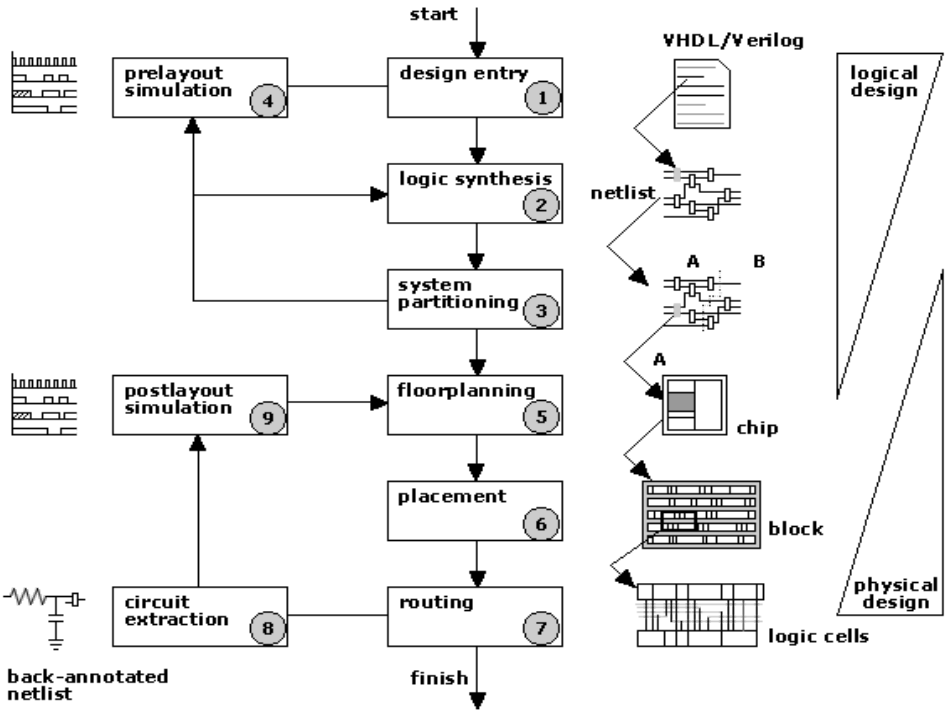


Figure 1: ASIC Chip Design Flow

Background

Camera Modules have been derived by smartphones industry to decrease the camera volume and increase the image performance, in particular resolution, low light performance, focus and stabilization. Figure 2 shows the current and forecasted transformation of the mobile camera functions.

For similar reasons to automotive, namely increasing usage of image analytics and improved performance and productivity, the security, medical and industrial market are currently thriving and all deserve specific analysis.

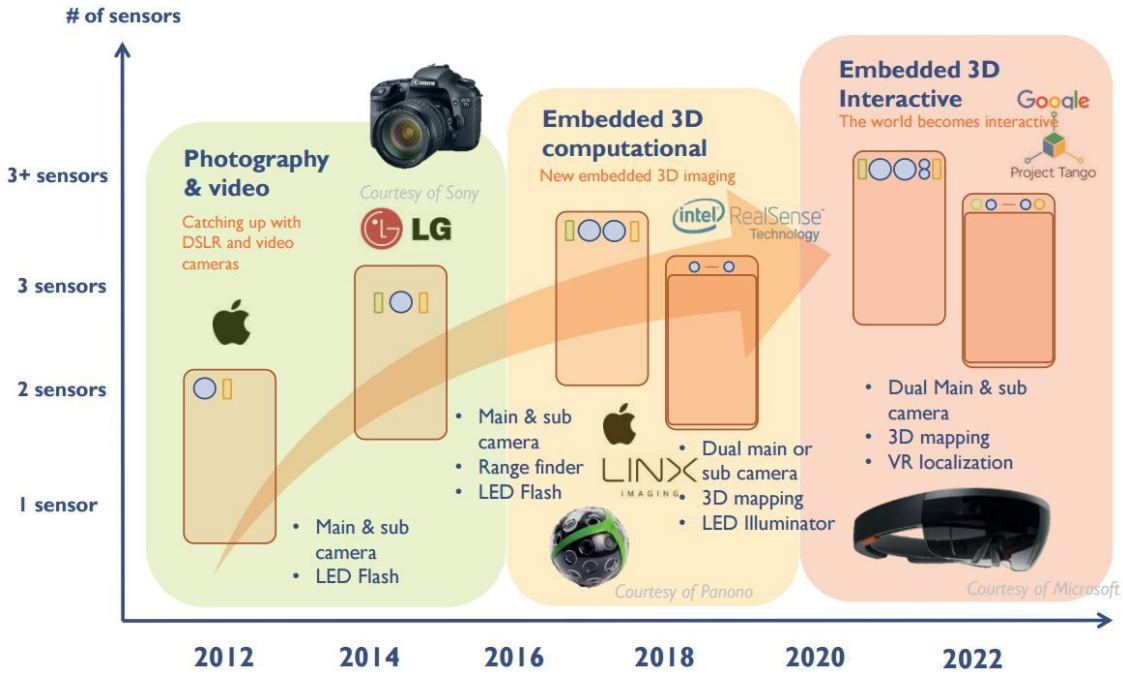


Figure 2: Transformation of Mobile Camera Function [2]

AutoFocus (AF) Module is one of the main modules for the current camera features. AF uses a sensor, a control system and a motor to focus on an automatically or manually selected point or area. Most modern SLR cameras use through-the-lens optical AF sensors. **Passive AF systems** determine correct focus by performing passive analysis of the image that is entering the optical system. **Contrast detection autofocus** is achieved by measuring contrast within a sensor field, through the lens. The intensity difference between adjacent pixels of the sensor naturally increases with correct image focus. The optical system can thereby be adjusted until the maximum contrast is detected. [3-5]

Design Requirements

You are required to build a detailed hardware design for an AutoFocus Module based on contrast detection algorithm. The system is built for grey-leveled camera (each pixel has range between 0 to 255) as shown in figure 3. The main objective of the project is building the Focus Enhancement Module.

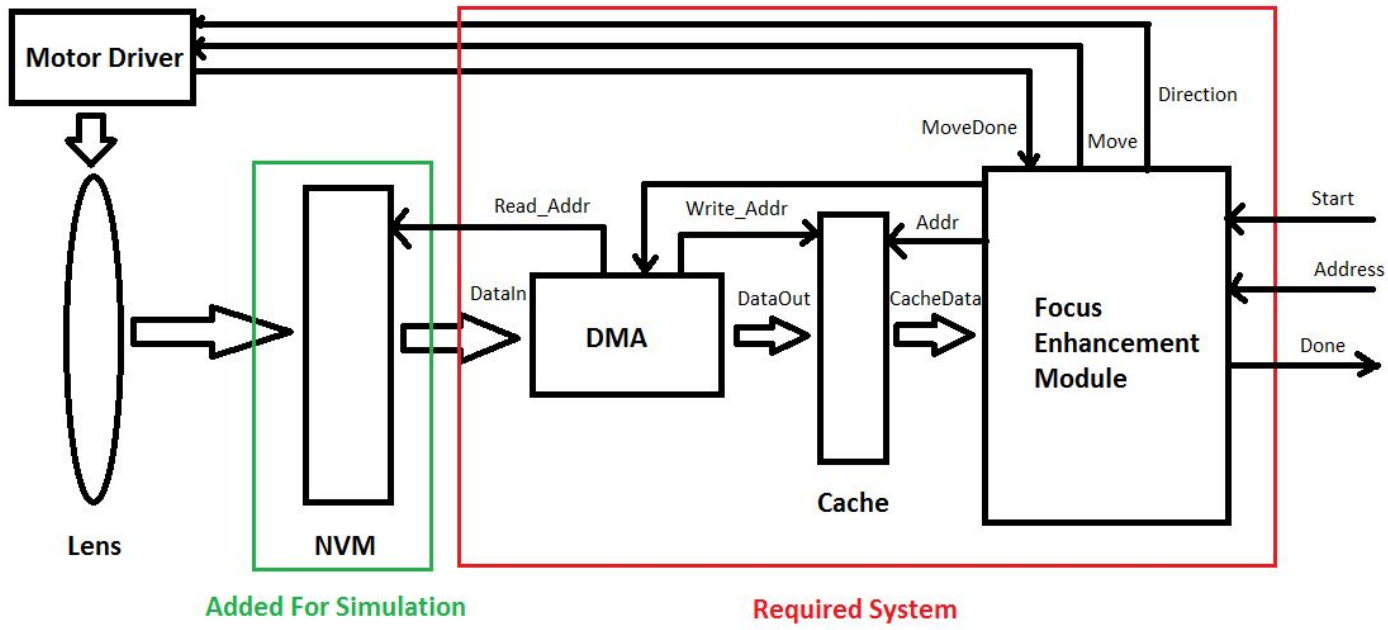


Figure 3: A simplified system design

Take in consideration that your design will be implemented in VHDL and synthesized in the next phases. So try to make the design as clear as possible to easily implement it. Prior optimization is a plus.

Application Scenario

Our camera company has assigned your team for designing & implementing AF module for a grey-level camera. The camera has a resolution of 256x256 pixels. The camera uses through-the-lens optical modules, so the image received from the lens are always saved in Nonvolatile Memory (NVM) module, where the image is saved row by row (i.e: 1st row is saved in memory locations from 0 to 255, 2nd row is saved in 256 to 511, and so on). The image index starts from the top left as pixel number (0,0).

The user could see the image at runtime before capturing the image (this module is out of our responsibility). When s/he wants to focus on a specific part of the image, s/he clicks on that part of the image. Then the camera CPU sends to the AF module a “Start” signal and the address of the top left pixel of the specific focus part (matrix of 16x16 pixels).

The AF module runs the contrast detection algorithm to move the lens (using Motor Driver) in or out till the specific part of the image becomes infocus (maximum contrast). Finally AF sends “Done” to the CPU.

Scenario Details

1. CPU sends Address = “focus_matrix” & Start = ‘1’
2. AF sends to DMA to read “focus_matrix”
3. DMA reads “focus_matrix” from NVM and save it in Cache
4. DMA sends Ack to AF
5. AF runs Contrast Detection Algorithm
6. AF sends Done=’1’ to CPU

Contrast Detection Algorithm

1. Load Focus Matrix
2. Compute Total Contrast
3. Set a Random Direction (in / out)
4. Move Lens with L_delta
5. Compute Total Contrast
6. If worse (New Total Contrast decreased)
    - Change Direction
7. Move Lens with L_delta
8. Compute Total Contrast
9. If worse (New Total Contrast decreased)
    - Finish the Algorithm
10. Else
    - Repeat from step #7

Computing Total Contrast

For each pixel in the Focus Matrix (16x16):

    Compute Contrast with all adjacent pixels
    Add the contrast to the Total_Sum

End loop;

System Specifications

The system should have the following I/O ports:

Port	Direction	Size
Clk	IN	1 bit
Rst	IN	1 bit
Start	IN	1 bit
FocusAddress	IN	Your choice
Done	OUT	1 bit
Direction	OUT	1 bit
Move	OUT	1 bit
MoveDone	IN	1 bit
NVM_Address	OUT	Your choice
NVM_Data	IN	128 bit

The NVM is an external memory (outside your system) that you will implement for simulation purposes. The NVM should have the following structure:

Port	Direction	Size
Clk	IN	1 bit
Rst	IN	1 bit
Address	IN	Your choice
Data	OUT	128 bit

You could add any additional I/O ports and modules according to your need, but you have to justify your design choices.

References for more Informations

1. Global Camera Modules Market Report 2015-2020 - The Total Camera Modules Market is Expected to Reach USD 36.95 Billion by 2020
2. Status of the CMOS Image Sensor Industry 2016: New Market and Technology Dynamics
3. https://en.wikipedia.org/wiki/Autofocus#Contrast_detection
4. https://graphics.stanford.edu/courses/cs178/applets/autofocusCD.html
5. https://cardinalpeak.com/blog/detecting-well-focused-images/

Rules & Regulations

- Team are 3-4 members.
- You are free to design your system as you want as long as you perform the required functionality.
- Your design should be modifiable to meet the design constraints in the next phases.
- Take care that your design is logically mappable to hardware or you will have to repeat it all again.
- Open your mind and don't limit yourself .
- You are not allowed to copy from any external resources in your implementation .
- You are allowed to consult external resources for Design but Do your OWN & you have to fully understand it.
- **Grades are based Mainly on Individual work + your team work . if you didn't work and the project was complete you will still get a zero grade. And I really mean it.**
- The Document is variable to change with a previous notification.

Deliverables

- Hardware Design Document:
  - Detailed Units Architecture with connections.
  - Detailed Sub-units Design in the logic gates Level.
  - Design assumptions and limitation
  - Your Names

Deadline: Thursday 24/4/2017 at Section Time

Discussion: will be scheduled later