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Realisation of Digital Memory Unit Using VHDL And FPGA

Soumen Pal¹, Srabani Roy², Jaga Bandhu Saha³, Rajaasree Naskar⁴, Surjo Saha⁵, Moumi Saha⁶

¹Assistant Professor, ²Technical Assistant, ^{3,4,5,6}Student, Department of Electronics & Communication Engineering, Narula Institute of Technology, Kolkata, India

Abstract: The design process involves defining the RAM's architecture using VHDL, which includes address decoding, data input/output mechanisms, and clock synchronization. The functionality is validated through simulation using VHDL simulation tools, ensuring accurate read and write operations. The synthesized design is then implemented on an FPGA kit, leveraging its reconfigurability to realize the RAM's hardware. Testing is performed to verify the functionality in a real-time environment, examining parameters such as read/write latency and data integrity. This project demonstrates the practical application of digital design principles, VHDL programming, and FPGA implementation techniques. The 128*8 RAM module serves as a foundational component for larger digital systems, offering scalable memory solutions for embedded and computational applications.

Index terms—Single-Port RAM, VHDL, FPGA, Memory Design, 128*8 Memory, Hardware, Description Language (HDL), FPGA Kit, Reconfigurable Logic.

I. INTRODUCTION

In modern digital systems, memory plays a crucial role in storing and retrieving data efficiently. Among various memory types, RAM (Random Access Memory) is widely used due to its fast read and write operations. A Single-Port RAM (SPR) is a memory configuration where both read and write operations cannot occur simultaneously but can be performed independently at different times. This makes single-port RAM an ideal solution for systems that require simple memory architectures with low resource consumption, such as embedded systems, microcontrollers, and digital signal processing applications.

RAM allows your computer to perform many of its everyday tasks, such as loading applications, browsing the internet, editing a spreadsheet, or experiencing the latest game. Memory also allows you to switch quickly among these tasks, remembering where you are in one task when you switch to another task. In the context of FPGA (Field-Programmable Gate Array) design, VHDL (VHSIC Hardware Description Language) is a popular language used to describe and implement digital circuits. This design aims to implement a Single-Port RAM memory unit using VHDL for an FPGA-based system. The Single-Port RAM will have a single access port for both reading and writing data, controlled by a write enable signal. FPGAs are programmable silicon chips with a collection of programmable logic blocks surrounded by Input/Output blocks that are put together through programmable interconnect resources to become any kind of digital circuit or system. The FPGA will be used to store data at specific memory locations, allowing read and write operations to occur based on control signals and the system clock. The objective of this design is to create a simple, efficient memory block that can be easily incorporated into FPGA systems requiring non-simultaneous read/write operations. The design will feature key components such as the address bus, data bus, clock signal, and write enable signal, which will be managed in the VHDL code to implement the desired functionality.[4]

II. LITERATURE SURVEY

A. Key concepts and Terminology

VHDL (VHSIC Hardware Description Language):-

VHDL is a hardware description language used to model and design digital systems. It allows engineers to describe the behavior and structure of electronic systems at various levels of abstraction. VHDL is widely used in the design, simulation, and synthesis of digital circuits for FPGAs and ASICs.

B. Key Features of VHDL:

- Concurrency: VHDL inherently supports concurrent execution, making it suitable for modeling parallel digital circuits.

- Modularity: Supports modular design, making complex design easier to manage.
- Simulation and Synthesis: Allows functional simulation to verify design correctness and synthesis to implement the design on hardware.
- Platform Independence: Portable across various simulation tools and FPGA/ASIC platforms.
- Rich Data Types: Supports user-defined data types, arrays, and enumerations. [1]

C. Digital Memory Unit: -Single-Port RAM Digital Memory:

A digital memory unit stores binary data that can be read or written. A single-port RAM is a type of memory where a single access point is used for both reading and writing operations.

Single-Port RAM Features:

- 1) Size: For a 128X configuration, the memory has 128 locations, each storing 8-bit data.
- 2) Addressing: 128 locations require a 7-bit address ($2^7=128$).
- 3) Data Bus Width: 8 bits for data in and data out.
- 4) Control Signals:
 - Write Enable (WE): Specifies whether to write or read data.
 - Clock (CLK): Synchronizes operations.
 - Chip Enable (CE): Activates the memory unit.

D. Synthesis of Digital Circuits

Synthesis:

Synthesis is the process of converting a high-level hardware description (e.g., VHDL code) into a low-level implementation suitable for FPGA or ASIC hardware.

Steps in Synthesis:

- 1) RTL (Register Transfer Level) Description: High-level design description using VHDL or Verilog.
- 2) Logic Optimization: Optimizes Boolean expressions and minimizes logic gates.
- 3) Technology Mapping: Maps the design to the target FPGA or ASIC technology.
- 4) Placement and Routing: Allocates physical resources (LUTs, flip-flops) and connects them on the FPGA. [7]

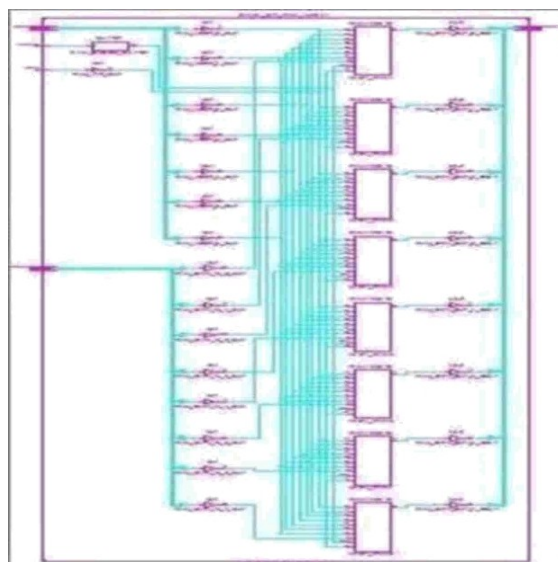


Fig1: Technology Schematic

III. RAM DESIGN USING YHDL

A. Basic Memory Structures

Early studies focused on the fundamental design of memory units such as ROM and RAM, outlining the architecture and operational principles (Wakerly, 2000; Mano, 1993). [9][10]

B. VHDLin Digital Design

Perry(2002)andAshenden (2008)providedcomprehensiveguidesonusingVHDLfordigitaldesign,highlighting itssyntax, semantics, and application in designing various digital components, including memory units.[11][12]sram1

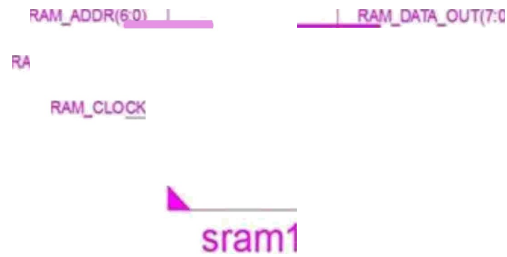


Fig.2showstheRTLSchematicofSinglePortRAMmemory.

IV. DESIGN SPECIFICATIONS

Fortheimplementationofthe128x8single-portRAMin VHDL,thefollowingdesignspecifications are considered:

- 1) RAM_CLOCK:theclocksignal forsequentiallywritingdatatothesingle-portRAM.
- 2) RAM_DATA_IN:8-bitinputdatatobewrittentoRAMattheprovidedinputaddressRAM_ADDRwhenitisenabled.
- 3) RAM_WR: WriteenablesignalforwritingtoRAM,onlyifRAM_WR=1,RAM_DATA_INiswrittentotheRAMattherisingedgeof the clock signal.
- 4) RAM_ADDR: 6-bitAddresswhere8-bitinputdataare written to anddata are read out. 5.RAM_DATA_OUT:8-bitoutput data read out fromtheprovidedinputaddressRAM_ADDR.[12]

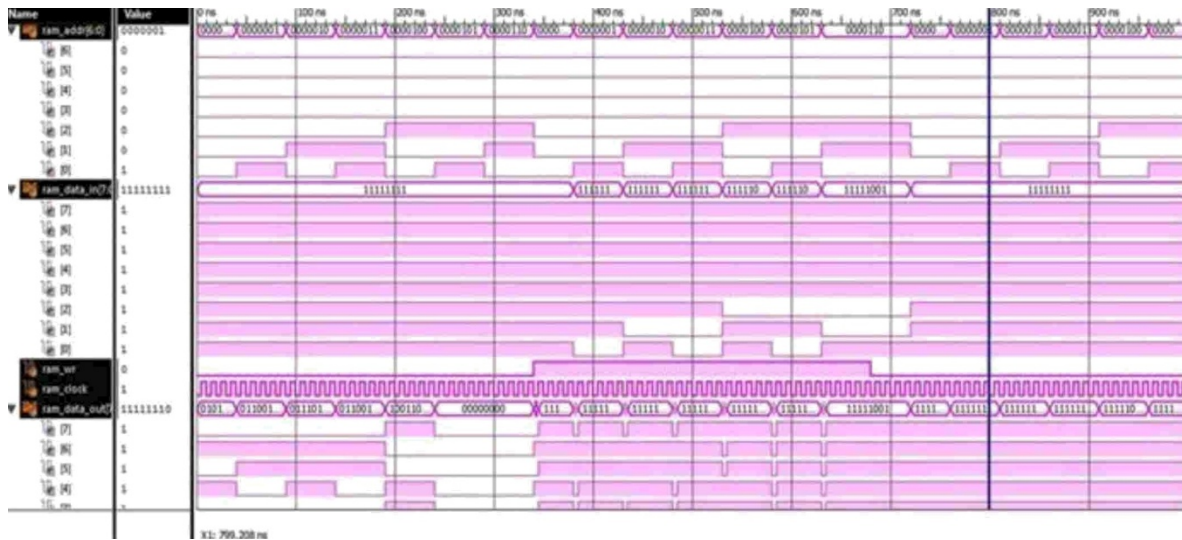


Fig3:SimulationresultofsingleportRAMinVHDL.

V. FPG ARE ALIZATION

Inthis design,we haveimplementedthe 1288 Single-Port RAMonagenericFPGAplatformusingVHDL.Below are the steps involved inthe design and implementation process:

- 1) VHDLDesign: Thememory unitwasdesignedusingVHDLcode, whichdefinesthebehavioroftheRAM. Thedesigninvolves specifying thememory size(128 locations, each with 8bits), address bus width, databus width, andcontrol signals suchas read/write enable.
 - EntityDeclaration:Thedesignstartswiththeentitydeclaration,whichdefinestheinputandoutputports.The inputs includetheclock, reset,address,datainput(for writing),andcontrolsignals.
 - Architecture: Thearchitecture sectiondescribestheinternallogic.Aprocessblockisusedtohandletheread/write operations, triggered by the clock and control signals.

- 2) **Synthesis and Simulation:** After writing the VHDL code, the design is synthesized using FPGA synthesis tools (e.g., Xilinx Vivado or Intel Quartus). The simulation of the design is carried out using tools like ModelSim to verify the functionality of the RAM.
 - **Testbench Creation:** A testbench is created to simulate the behavior of the RAM. This testbench applies various address, data, and control signals to test the read and write operations under different conditions.
- 3) **FPGA Implementation:** Once the design passes simulation, the synthesized bitstream is loaded onto an FPGA board (e.g., Xilinx or Intel FPGA). The FPGA kit is connected to a testing setup where input values are applied, and the output is verified. [6]



Fig4:FPGA interface

VI. APPLICATIONS OF SINGLE PORT RAM

Single-port RAM is essential in many embedded system designs, especially where simple memory solutions are required. The applications include:

- 1) **Embedded Systems:** Single-port RAM is often used in microcontrollers, where simple data storage and retrieval are needed for operations like data buffering and stack management.
- 2) **Data Storage:** The 128*8 memory can be used in applications like data logging, caching, or temporary storage for processing in a variety of electronic devices, including IoT devices.
- 3) **Control Systems:** In control systems, where fast access to memory is required to store and retrieve sensor data, a single-port RAM can efficiently handle these tasks.
- 4) **Signal Processing:** In FPGA-based signal processing systems, a single-port RAM can be used to store intermediate results, such as in digital filters or Fourier transforms.
- 5) **Prototyping:** FPGA implementations of RAM modules allow designers to quickly prototype systems, making single-port RAM a valuable resource in early-stage product development.

VII. CONCLUSION

In this paper, we have successfully designed and implemented a 128*8 Single-Port RAM using VHDL and an FPGA kit. The design leverages VHDL's ability to describe hardware behavior, while the FPGA provides the hardware platform to validate the design. The system performs read and write operations correctly, and the design can be expanded or integrated into more complex systems. This implementation serves as a useful memory solution for embedded systems, prototyping, and applications requiring efficient data storage.

VIII. FUTURE ENHANCEMENTS

The current design of a single-port RAM can be enhanced in several ways to meet evolving demands in digital systems. One of the most promising enhancements is the development of a dual-port RAM, enabling simultaneous read and write operations, which is critical for applications requiring high-speed data processing, such as video processing or real-time analytics. Additionally, the design can be made more flexible by introducing parameterization, allowing users to dynamically configure memory size during synthesis to suit specific application requirements.

Incorporating error detection and correction (ECC) mechanisms, such as Hamming Code, would significantly enhance the reliability of the RAM, ensuring data integrity in critical systems. Furthermore, power optimization techniques, like clock gating, could be implemented to reduce energy consumption, making the design more suitable for energy-sensitive applications. To improve data transfer efficiency, support for burst read and write operations could be added, which is particularly advantageous in high-speed communications systems.

Another area of enhancement lies in memory initialization, where the RAM could be preloaded with specific data from an external file, improving its utility in simulations and practical applications. Advanced integration could also be achieved by adding support for widely used communication protocols like AXI or Avalon, allowing seamless connectivity with modern SoC architectures. Built-in self-test (BIST) mechanisms could further enhance the design by enabling automated testing and debugging, ensuring reliability during deployment.

For more complex systems, the RAM could be integrated with soft-core processors, such as Xilinx MicroBlaze or Intel Nios II, to provide embedded processing capabilities. Finally, performance can be optimized by leveraging FPGA-specific features, such as using block RAMs (BRAMs) or distributed RAMs, to improve speed and resource utilization. These enhancements not only expand the scope of applications but also improve the performance and reliability of the RAM design. [2][5]

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