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FPGA Based Logic Analyzer

Yewale Samir Santosh[1] Zaware Shivam Maruti[2] Vite Aditya Santosh[3] Assistant Professor P.S Bugade[4]

[1,2,3]Undergraduate Student,Electronics & Telecommunication Engineering, Jaihind College Of Engineering Kuran, Maharashtra,India,

[4].Assistant Professor,Electronics & Telecommunication Engineering, Jaihind College Of Engineering Kuran, Maharashtra

Abstract- A logic analyzer is an electronic testing and debugging device used to observe multiple digital signals simultaneously. This project describes an FPGA-based logic analyzer that captures high-speed digital signals, stores the captured data and transfers it to a computer for waveform display. The system can be used to analyze digital communication signals such as UART, SPI and I^2C.Digital signals from an external circuit are supplied to the FPGA through digital input pins. The FPGA samples the signals using its internal clock and records each input as HIGH (1) or LOW (0). A trigger circuit can detect a selected event, such as a rising or falling edge, so the system can focus on a particular signal event. Captured data is stored temporarily in FPGA internal memory such as BRAM or FIFO.After capture, the data is transferred to a PC through a UART or USB interface. PC software converts the received data into timing waveforms. The user can observe signal changes, compare the timing relationship between signals and identify problems such as incorrect timing, missing pulses or communication errors. The project aims to provide a flexible and comparatively low-cost tool for digital circuit debugging.

Keywords: **FPGA, Logic Analyzer, Digital Signal Acquisition, BRAM, FIFO, UART, USB, SPI, I^2C, Timing Waveforms.**

I. INTRODUCTION

An FPGA-Based Logic Analyzer is a digital electronic testing and debugging system designed to capture, monitor, and analyze digital signals in real time. It is developed using a Field Programmable Gate Array (FPGA), which provides high-speed processing, parallel operation, and flexible hardware configuration. The main purpose of this project is to observe the behavior of digital circuits by capturing logic signals such as 0 (LOW) and 1 (HIGH) and displaying their timing information for analysis.

A logic analyzer is an important instrument used in digital electronics and embedded system development. It helps engineers and students understand the operation of digital circuits by monitoring multiple signal channels simultaneously. Unlike a conventional oscilloscope, which mainly displays analog voltage waveforms, a logic analyzer focuses on digital signal transitions and timing relationships between different signals. It is useful fordebugging communication protocols and identifying errors in digital systems.

The stored information is then processed and displayed in the form of digital waveforms. The system can monitor signal transitions, detect HIGH and LOW states, and analyze the timing relationship between multiple digital signals.

The proposed FPGA-based logic analyzer can be implemented using Verilog HDL or VHDL. The design includes important modules such as a clock generator, signal acquisition unit, trigger control unit, memory storage unit, and waveform display unit. These modules work together to capture and analyze digital signals efficiently. The FPGA provides flexibility to modify the design according to different requirements and supports real-time digital signal monitoring.

The main objective of this project is to develop a low-cost, compact, and efficient digital signal analysis system that can be used for educational purposes, laboratory experiments, and hardware debugging. This project helps in understanding FPGA architecture, digital system design, Verilog HDL programming, and real-time signal processing. It also provides practical knowledge of digital circuit testing and troubleshooting.

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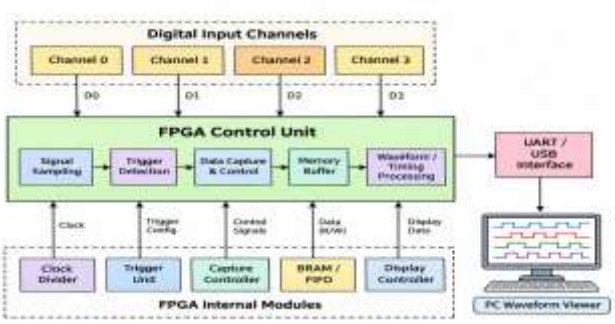
Overall, the FPGA-Based Logic Analyzer is a useful digital testing tool that demonstrates how FPGA technology can be used to capture, monitor, and analyze multiple digital signals efficiently.

Working:

The FPGA-Based Logic Analyzer works by capturing, storing, and analyzing multiple digital input signals using a Field Programmable Gate Array (FPGA). Initially, the system receives digital signals from the external circuit through different input channels. These signals are represented as binary values, either 0 (LOW) or 1 (HIGH). The FPGA samples these input signals according to a predefined clock frequency. After receiving the signals, the signal acquisition module continuously monitors the input channels and detects changes in their logic levels. The trigger control module checks for a predefined condition, such as a rising edge, falling edge, or a particular logic pattern. When the trigger condition is satisfied, the FPGA starts or continues capturing the required signal data.

The captured digital data is stored in the internal memory of the FPGA for further processing. The control unit manages the sampling process, memory operation, and data transfer. After capturing the required data, the stored information is processed and converted into waveform patterns. Finally, the digital waveforms are displayed on a computer screen or supported display interface, allowing users to observe signal transitions and timing relationships between different channels. By analyzing these waveforms, users can identify errors, timing issues, and unexpected behavior in digital circuits.

Thus, the FPGA-Based Logic Analyzer provides an efficient method for monitoring and debugging digital systems with high-speed signal acquisition and real-time processing capabilities.



Advantages:

- High-Speed Operation: Captures and analyzes digital signals at high speeds.
- Multiple Channel Support: Monitors multiple digital signals simultaneously.
- Real-Time Monitoring: Captures signal transitions in real time.
- Flexible Design: FPGA can be reprogrammed according to project requirements.
- Accurate Signal Analysis: Helps identify timing errors and unexpected logic changes.
- Low Cost: Can be developed at a lower cost than many commercial logic analyzers.
- Compact Size: Can be implemented using a small FPGA development board.
- Easy Debugging: Helps engineers troubleshoot digital circuits and embedded systems.
- Parallel Processing: FPGA supports simultaneous processing of multiple signals.
- Educational Purpose: Provides practical knowledge of digital electronics, FPGA architecture, and Verilog HDL.

Disadvantages:

- Limited Memory: Internal FPGA memory restricts the amount of data that can be stored.
- Design Complexity: Requires knowledge of FPGA architecture and HDL programming.
- Limited Input Channels: The number of channels depends on available FPGA pins.
- High-Speed Limitations: Maximum sampling frequency depends on the FPGA hardware.
- Power Consumption: Continuous operation and high-speed processing may consume more power.
- Hardware Dependency: Performance depends on the selected FPGA development board.
- Interface Complexity: Connecting the FPGA to a PC or display may require additional hardware and software.
- Debugging Difficulty: Errors in HDL code and timing constraints can be difficult to identify.
- Limited Advanced Features: A basic design may not support advanced protocol decoding.
- Initial Development Time: Designing, testing, and verifying the complete system can take considerable time.

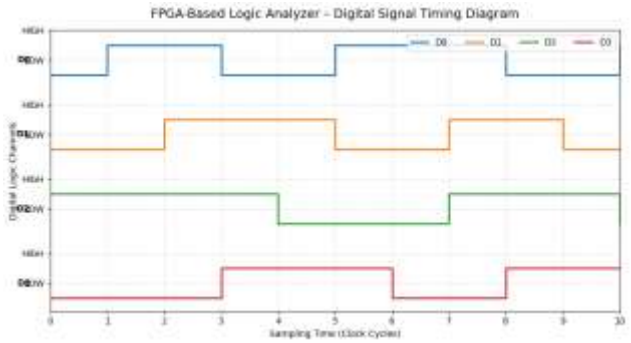


Chart -1:FPGA-Based Logic Analyzer – Digital Signal Timing Waveform



Figure 1:FPGA-Based Logic Analyzer – Hardware Implementation Model

II. CONCLUSION

The FPGA-Based Logic Analyzer is an efficient and flexible digital testing system developed for capturing, monitoring, and analyzing multiple digital signals in real time. The project demonstrates the use of FPGA technology for high-speed signal acquisition, trigger detection, data storage, and waveform generation. By using Verilog HDL, different functional modules can be designed and integrated to perform digital signal analysis accurately. The system helps identify signal transitions, timing errors, and unexpected behavior in digital circuits. It also provides practical knowledge of FPGA architecture, digital system design, and hardware description languages. Overall, this project offers a cost-effective and reliable solution for digital circuit debugging and educational laboratory applications. Future improvements can include increasing the number of input channels, improving sampling frequency, and adding advanced communication protocol decoding features.

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