FPGA Devices: Survey and Analysis

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***Abstract*—Field Programmable Gate Arrays (FPGAs) have emerged as a powerful and versatile technology for implementing digital systems. This seminar paper provides a comprehensive survey of FPGA devices, Covering their manufacturers, architecture, design methodology, tools, and applications. The paper also discovers the challenges and opportunities associated with FPGAs.**

I. Introduction

In modern computing, Field Programmable Gate Arrays (FPGAs) are known as versatile and dynamic component in between traditional hardware and software solutions. Unlike non reconfigureable architecture integrated circuits, field programmable gate arrays offer reconfigurability and programmability allowing the customization of digital circuits based on specific application requirements.Over the past few decades FPGAs have evolved from telecommunication and signal processing to emerging technologies like artificial intelligence and edge computing.

The special thing about FPGAs is that they can change how they work without needing physical changes. This makes the FPGAs useful. This has positioned FPGAs as key enablers for rapid prototyping, algorithm acceleration, and system-level design. As the demand for high-performance computing concontinues to rise the FPGAs have become the integral components in many different electronic systems. This research paper aims to survey and analyze the current state of the FPGAs by observing their manufacturers, architecture,design methodology, and applications

II. Overview of all manufacturers

A. AMD Xilinx

Founded in Silicon Valley in 1984, Xilinx's primary headquarters is in San Jose, USA. The company also maintains offices in Longmont, USA; Dublin, Ireland; Singapore; Hyderabad, India; Beijing, China; Shanghai, China; Brisbane, Australia; Tokyo, Japan; and Yerevan, Armenia [1].

According to the former CTO Bill Carter, the name Xilinx refers to the chemical symbol of silicon. And the other part of the name(Linx) refers to the links that connects programmable logic blocks [1].

According to recent history the first product based on 2.5D layered silicon to produce larger FPGAs than could be constructed using conventional monolithic silicon was the Virtex-7 2000T, which the company introduced in 2011. Then, Xilinx modified the technology to integrate previously distinct parts into a single chip. To increase bandwidth capacity while consuming less power, the company first combined an FPGA with transceivers based on heterogeneous process technology [1].

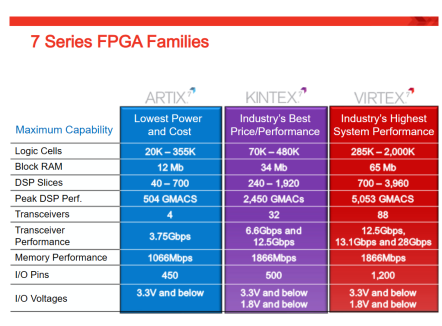
In 2018, Xilinx upgraded its XQ UltraScale+ defense-grade products to use TSMC's advanced 16nm FinFET manufacturing process. These products were the industry's first Defense-grade heterogeneous multi-processor SoC devices and included XQ Zynq UltraScale+ MPSoCs, RFSoCs, Kintex, and Virtex FPGAs [1].

AMD and Xilinx agreed on October 27, 2020, to exchange stocks for Xilinx, with a 35 billion USD valuation. Closing of the deal was scheduled for the end of 2021. On April 7, 2021, their stockholders gave their approval for the purchase. The agreement came to an end on February 14, 2022.Following the completion of the acquisition, all Xilinx products are now co-branded as AMD Xilinx; this consolidation began in June 2023 and unites all Xilinx products under AMD's branding [1].

Past few years and until now AMD Xilinx has been the leader in the market of FPGAs. It controls more than 50 percent of the world's FPGA market share. In the future AMD will target the high-performing computing market with Xilinx FPGAs.

- Xilinx Virtex 7
- Xilinx Artix 7
- Xilinx Kintex 7
- Xilinx Ultrascale+

Some of the famous AMD Xilinx FPGAs are mentioned above.Refer to Fig.1 For more information Such as logic cells, power consumption. I/O Pins on Different FPGAs.


7 Series FPGA Families

Maximum Capability	ARTIX 7 Lowest Power and Cost	KINTEX 7 Industry's Best Price/Performance	VIRTEX 7 Industry's Highest System Performance
Logic Cells	20K – 355K	70K – 480K	285K – 2,000K
Block RAM	12 Mb	34 Mb	65 Mb
DSP Slices	40 – 700	240 – 1,920	700 – 3,960
Peak DSP Perf.	504 GMACS	2,450 GMACs	5,053 GMACS
Transceivers	4	32	88
Transceiver Performance	3.75Gbps	6.6Gbps and 12.5Gbps	12.5Gbps, 13.1Gbps and 28Gbps
Memory Performance	1066Mbps	1866Mbps	1866Mbps
I/O Pins	450	500	1,200
I/O Voltages	3.3V and below	3.3V and below 1.8V and below	3.3V and below 1.8V and below

Fig. 1. FPGA Overview[11]

B. Intel Altera

Intel's history in the field of programmable logic predates the purchase of Altera in 2015. Before Intel acquired Altera, the two companies had a long-standing collaboration. Until Altera eventually acquired Intel's PLD division in 1994, Intel had previously licensed Altera's technology for use in its programmable products [2].

Altera was founded in 1983 by Rodney Smith, Robert Hartmann, James Sansbury, and Paul Newhagen. Starting in December 2012, the company used a fully depleted silicon-on-insulator (FDSOI) chip manufacturing technique to build system on a chip FPGA device. These devices combined FPGAs and whole ARM-based hard processor systems into a single unit [3].
inevitably Intel's FPGAs and SoCs of today are very different from the EP300 of the past. With today's options from Intel, developers may tackle a variety of applications, from low-power consumer applications to industrial and automotive solutions to high-performance data centers. These include FPGAs and SoCs [2].

Intel Altera is the second leader of the current world FPGA market. It controls around thirty three percent of the FPGA market share worldwide. Altera covers the low-end, mid-end, and high-end market with complex programmable logic devices and with high end field programmable gate arrays.

- Arria
- Stratix
- Max
- Cyclone
- Agilex

Above mentioned FPGAs are made by Intel altera. Refer to below mentioned Fig 2 for more information about low cost, mid-range, and high end FPGAs

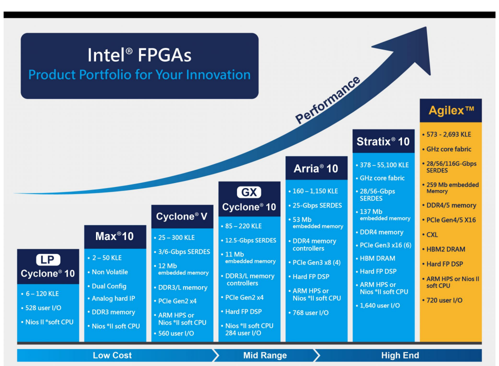


Fig. 2. Intel FPGAs product portfolio[12]

C. Lattice Semiconductor

Lattice Semiconductor also known as the world's low-power FPGA leader was founded in 1983 in Hillsboro United States by Norm Winningstad. In July 1987 Company went bankrupt due to early struggles. Sixty two days after declaring bankruptcy the company emerged from it and restructured the company and moved its headquarters in to an unincorporated area. Even though the year after company went from hundred and forty employees to sixty four employees, it managed to post a record revenue [4].

Lattice is mainly aiming at small, low power FPGAs. The company also offers programmable mixed-signal and interconnect products, along with associated software and intellectual property (IP). Key product lines offered by Lattice include the general-purpose FPGAs in the ECP and Certus-NX series, the video bridging and processing-focused CrossLink FPGAs, the low-power ICE FPGAs, and the control and security-focused MachXO FPGAs. These products are applied across a range of scenarios, such as cloud computing and edge computing [4].

Currently, over 700 employees are working for lattice semiconductor worldwide and the company's headquarters is in a high-tech area in Hillsboro United States also known as the Silicon Forrest. After AMD's acquisition of Xilinx in 2022 Lattice Semiconductor became the only fully independent large-scale FPGA Manufacturer in the World. As of today, it controls around 10 percent of the world's FPGA market Share [4].

- Certus
- Mach
- Avant
- ECP
- Cross Link
- Ice

Above mentioned are some of the most popular FPGAs produced by Lattice Semiconductor. Refer to the below mentioned Fig 3. for more information about the crosslink FPGAs' power consumption compered to other manufacturers.

	Lattice	Xilinx	Intel
Device	CrossLink-NX-40	Spartan-7 50	Cyclone 10LP 40
0 MHz	34.6 mW (1x)	358 mW (10.0x)	244 mW (7.0x)
1 MHz	36.2 mW (1x)	360 mW (9.8x)	247 mW (6.8x)
200 MHz	248.6 mW (1x)	680 mW (2.7x)	880 mW (3.5x)

Fig. 3. Crosslink FPGAs Power consumption Compared with others[13]

D. Microsemi

Microsemi was an American semiconductor company that provided a vast range of semiconductors and system solutions for the aerospace, defense, communication, and industrial market. The company was founded in 1959 in the United States by Arthur Feldon and Steve Manning [5].

The Company mainly focuses on producing High-performance and radiation-hardened analog mixed-signal integrated circuits (ICs), FPGAs,SoCs (system-on-chips) and ASICs (application-specific integrated circuits), and Power management products [5].

If we take a look at the markets of Microsemi it has three main markets for their products. such as Aerospace and defense, Communications, and Industrial.

1) Aerospace and Defence: Microsemi's high-performance and radiation-hardened analog mixed-signal ICs are used in avionics systems to provide precision timing, data conversion, and signal processing [6]. It also provides radar solutions including RF front-ends, analog-to-digital converters (ADCs), and digital signal processors (DSPs). These solutions are used in a variety of radar applications, such as air traffic control, weather radar, and military radar.[7] Microsemi's security solutions include FPGAs, SoCs, and ASICs that are required to meet the stringent security requirements of aerospace and defense applications. These solutions are used in a variety of applications, such as secure communications, encryption, and authentication [8].

2) Communications: Microsemis communication solutions are used in many applications. Such as Wireless Communication(WIFI, LTE,5G), Industrial Communication(Industrial networking protocols, Remote I/Os), and Data Center.

III. FPGA Architecture

The architecture of a FPGA is designed to maximize programmability and flexibility.It typically consist of the below mentioned Components.

- Configurable Logic Blocks(CLBs)
- Programmable Interconnects
- Input/Output Blocks
- Clock Management
- Embedded Memory
- Specialised Blocks

1) Configurable Logic Blocks(CLBs): At the core of the FPGA architecture are Configurable Logic Blocks.CLBs consist of look-up tables, Multiplexers, Flip Flops and other elements. Look-up tables are providing the ability to implement combinational logic which allows the user to define specific functions for the FPGA

2) Programmable Interconnect(PIN): FPGAs use a grid of programmable interconnects for routing of signals between CLBs.These interconnects can be dynamically configured.

3) Input/Output Blocks: Input/Output blocks are used to interface with the external world by connecting FPGA to Input and Output devices. These blocks can be configured to adapt to specific interface requirements.

4) Clock Management: FPGAs include resources for clock management. Such as Phace-locked loops and Delay locked loops. These resources enable the control over the clock signals.

5) Embedded Memory: Many FPGAs incorporate embedded memory blocks, Including Block Ram and Distributed Ram. These resources can be used for data storage, memory-intensive tasks, and buffering. Helps in enhancing the FPGAs' overall performance.

6) Specialised Blocks: Depending on the FPGA there can be specialized blocks integrated into the architecture. As an example digital signal processing blocks are specialized arithmetic units. In Fig 4. you can see the internal structure of a Field Programmable Gate Array.

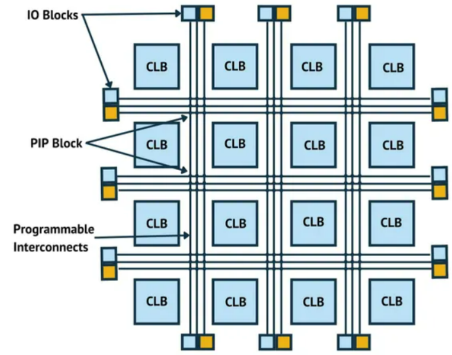


Fig. 4. Internal structure of a FPGA[14]

IV. Design methodologies and tools

There's a structural approach on field programmable gate arrays to develop a digital circuit. The process begins with the design specifications. Where the desired functionality and the performance requirements are defined. After this stage, the designer uses high-level hardware description languages(HDLs), as an example verilog or VHDL to create a register transfer level representation of the design. Once the RTL stage is done designers use synthesis tools to map the HDL into a netlist. After that designers use special tools to figure out where to put the different parts of the design on the FPGA chip and connect them together. Once this is done the designers check the timing to make sure everything works as fast or as slow as needed. After that, a special file will be made(the bitstream generation). Bitstream is the file that is going to be uploaded to the FPGA, giving the instructions about the job. Throughout this whole process testing tools are used to check if the design is correct and works properly. It helps to catch mistakes in the early stages.

A. Tools

Several tools are used throughout the FPGA design process.Such as High level synthesis tools

- Xilinx Vivado
- Synopsys Design Compiler

Place and route tools

- Xilinx Vivado Place and Route
- Synopsis IC Compier

Simulation tools

- Xilinx Vivado Simulator
- Cadance Model Sim

FPGA programming tools

- Xilinx Vivado Programmer
- Synopsys Design Compiler Programmer

V. Applications of FPGAs

There is a wide range of fields in which FPGAs are applied, including audio-video processing, image processing, signal processing, and implementation of various algorithms. In the future, it's expected that FPGAs will be used in oil, gas, finance, and many other industries. There have been a lot of changes in the FPGA architecture since 1985. These changes aim to minimize the distinctions between FPGAs and ASICs by enhancing their versatility and performance [9].

A. *Artificial Intelligence*

In artificial intelligence deep neural networks require powerful and energy-efficient tools.High end artificial intelligence devices are powered up by deep neural networks. As an example, P-Neuro an energy-efficient accelerator is way faster on FPGA than on a regular chip(GPU) and it uses much less energy too even though the regular chips run at a higher speed. The efficiency of FPGAs in terms of energy consumption is evident from the comparison table, surpassing all counterparts except for ASICs [9].

B. *Space Technology*

In Satellite Systems FPGA systems are used to improve the overall performance of communication systems by performing onboard processing activities including data compression, encryption, and signal processing because of their reconfigurable nature, they may be updated and modified while in flight, guaranteeing that they can adapt to changing mission needs.FPGAs are also essential for implementing complex control algorithms that allow accurate movements and autonomous decision-making capabilities.FPGAs help with real-time data processing and analysis in scientific missions which makes it easier to quickly and accurately gather data from space instruments. Furthermore, FPGAs are resilient to the harsh radiation and extreme temperature conditions of space, making them reliable components in space-borne electronics.

C. *Defence Systems*

The defense system uses FPGAs because of their fast data processing capabilities. It also provides great safety and high performance and integration. The risk is reduced because of the anti-tamper technology. FPGAs are also utilized in the electronic warfare systems, where ECCM is a key factor in advancements [9].

D. *Renewable Energy Systems*

In a solar charging system, it is essential for the solar panel to constantly face itself towards the sunlight to ensure that sunlight strikes the silicon or the solar panel perpendicularly. To achieve this, the sensor provides feedback to the FPGA, and the controller embedded in the FPGA responds by adjusting and rotating the solar panel accordingly.FPGAs also find application in systems that utilize powerful electromagnetic waves to break down limescale deposits, preventing pipe oxidation. Additionally, sensor-based FPGA systems are capable of detecting toxic gases, showcasing the versatility of FPGA technology in various applications. In Fig 5. you can find various applications of FPGA [9].

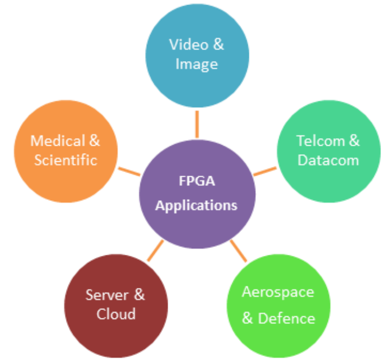


Fig. 5. Various Applications of FPGA[15]

VI. Challengers and Opportunities

The ongoing reduction in the size of CMOS processors has led to a growing set of challenges at the transistor level. These challenges have become more critical, prompting FPGA architects to address them strategically in order to minimize their impact on FPGA users. Soft errors and manufacturing defects are two of these issues.

The reduction in device sizes has given rise to a growing concern known as soft errors, where ionizing radiation disrupts circuit-stored data. These errors persist until new data is written. Soft errors can originate from various sources, initially from radioactive impurities in device packages and more recently from cosmic radiation interacting with silicon nuclei or insulator materials. Technology scaling exacerbates the soft error issue due to voltage scaling and reduced node capacitance, lowering the charge threshold needed to corrupt data [10].

Another primary challenge associated with FPGAs is the design complexity. Unlike general-purpose processors, which follow a predefined architecture, FPGAs allow the designer to create a custom circuit layout. This flexibility comes at the cost of increased complexity, as the designer must carefully consider the placement and routing of logic elements, as well as the allocation of memory resources. The design process for FPGAs is often iterative, requiring multiple design cycles to optimize the performance and resource utilization of the circuit.

Field-Programmable Gate Arrays (FPGAs), renowned for their adaptability in digital design, present challenges in power consumption. The dynamic nature of FPGAs, allowing for frequent reconfiguration, introduces notable dynamic power consumption, particularly in applications prioritizing energy efficiency. Moreover, as FPGA designs grow in complexity, static power consumption, or leakage power, becomes a significant concern, impacting overall energy usage, especially in idle states. Addressing these challenges requires a focus on power-aware design methodologies, exploring low-power FPGA architectures, and optimizing reconfiguration processes. Efforts in these areas are crucial to ensuring the sustainable integration of FPGAs in applications where power efficiency is paramount.

VII. Conclusion

In conclusion, this seminar paper has provided a comprehensive survey and analysis of Field-Programmable Gate Arrays (FPGAs), Researching their versatile applications, evolving architectures, and critical considerations. Throughout the exploration, it became evident that FPGAs play a pivotal role in diverse fields, ranging from audio and video processing to signal processing, and beyond. The paper discussed the challenges associated with the continued scaling of CMOS processes, emphasizing issues such as soft errors that FPGA architects must address to enhance user experience.Again the challenges such as power consumption, design complexity, were addressed, offering insights into the hurdles that designers may encounter. Concurrently, opportunities for advancements in FPGA technology were identified, including the potential for improved performance, energy efficiency, and novel applications.

In the end, this paper shows that FPGAs are powerful tools with a lot of potential. As technology keeps advancing, FPGAs will likely become even more useful in different fields. This seminar paper gives us a good starting point to understand FPGAs and their role in the exciting future of electronics.

VIII. Affidavit

I hereby confirm that I have written this paper independently and have not used any sources or aids other than those indicated. All statements taken from other sources in wording or sense are clearly marked. Furthermore, I assure that this paper has not been part of a course or examination in the same or a similar version.

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Last Name, First Name

Lippstdat,23/12/2023
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Location, Date

Unterschrift
Signature

References

[1] Xilinx (2023) Wikipedia. Available at: https://en.wikipedia.org/wiki/XilinxCompany overview (Accessed: 14 December 2023). .

[2] Taylor, A. (2022) Intel fpgas overview, Adiuvo Engineering. Available at: https://www.adiuvoengineering.com/post/intel-fpgas-overview (Accessed: 14 December 2023).

[3] Altera (2023) Wikipedia. Available at: https://en.wikipedia.org/wiki/Altera (Accessed: 14 December 2023).

[4] Lattice Semiconductor (2023) Wikipedia. Available at: https://en.wikipedia.org/wiki/Lattice Semiconductor (Accessed: 15 December 2023).

[5] Microsemi (2023) Wikipedia. Available at: https://en.wikipedia.org/wiki/Microsemi (Accessed: 15 December 2023).

[6] Avionics market size analysis, share, trends and industry growth driver 2030 (no date) MarketsandMarkets. Available at: https://www.marketsandmarkets.com/Market-Reports/commercial-avionic-system-market-138098845.html (Accessed: 15 December 2023).

[7] Radar Systems Market Emerging Trends and future outlook 2030 (no date) MarketsandMarkets. Available at: https://www.marketsandmarkets.com/Market-Reports/radar-system-market-207283650.html (Accessed: 15 December 2023).

[8] India Aerospace and amp; Defense Market Size - industry analysis report 2024 (no date) Global Market Insights Inc. Available at: https://www.gminsights.com/industry-analysis/india-aerospace-defense-market (Accessed: 15 December 2023).

[9] S. Gandhare and B. Karthikeyan, "Survey on FPGA Architecture and Recent Applications," 2019 International Conference on Vision Towards Emerging Trends in Communication and Networking (ViTECoN), Vellore, India, 2019, pp. 1-4, doi: 10.1109/ViTECoN.2019.8899550.

[10] FPGA architecture: Survey and Challenges - University of Toronto. Available at: https://www.eecg.toronto.edu/ jayar/pubs/kuon/foundtrend08.pdf (Accessed: 19 December 2023).

[11] 7 series FPGA overview part PPT download (no date) SlidePlayer. Available at: https://slideplayer.com/slide/5967461/ (Accessed: 20 December 2023).

[12] https://www-gfec-production.onemacnica.com/en/products/semiconductor/intel-fpga

[13] Lattice blog (no date) CrossLink NX FPGAs. Available at: https://www.latticesemi.com/ja-JP/Blog/2020/09/30/16/26/CrossLink NX FPGAs (Accessed: 20 December 2023).

[14] Rao, R. (no date) FPGA design: A comprehensive guide to mastering field-programmable gate arrays, Wevolver. Available at: https://www.wevolver.com/article/fpga-design-a-comprehensive-guide-to-mastering-field-programmable-gate-arrays (Accessed: 20 December 2023).

[15] Hardwarebee (2022) FPGA applications, HardwareBee. Available at: https://hardwarebee.com/fpga-common-applications/ (Accessed: 20 December 2023).