ANALYSIS OF AVIATION INFORMATION DISPLAY METHODS AND THEIR IMPLEMENTATION AS A SYSTEM ON CHIP

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Abstract. This paper analyzes cockpit display systems in aviation, examining their evolution, classification, and implementation as system-on-chip solutions. It explores display technologies, assessing their suitability for civil and military aviation. The classification of displays based on information type, positioning, and technology provides a framework for understanding their roles. The study also investigates avionics architectures, highlighting the advantages of SoC implementations. The research underscores the benefits of SoC-based display processing units in enhancing efficiency, reducing power consumption, and improving situational awareness. Challenges such as computational demands and integration complexities are discussed. The findings contribute to advancing cockpit display technologies, supporting the development of more adaptable and sophisticated aviation systems.

Keywords: Cockpit display systems, Aviation electronics, Head-up display, HUD, Head-mounted display, HMD, Head-down display, HDD, System-on-chip, SoC, Avionics architecture.

1. Introduction

Cockpit display systems are essential for enabling pilots, both civilian and military, to safely operate aircraft and carry out their missions. These systems provide visual presentations of crucial data from the aircraft's sensors and systems, equipping the pilot with primary flight information, navigation data, engine metrics, airframe status, and warning notifications. Military pilots have access to an even broader range of information, including infrared imaging sensors, radar feeds, tactical mission data, weapon aiming parameters, and threat warnings. The comprehensive, real-time visual representation of the aircraft's state and its operating environment is vital for the successful operation and mission execution of any aircraft. Pilots can rapidly absorb and process substantial amounts of visual information [1], but it is crucial that the information is displayed in a manner that can be readily assimilated, with unnecessary data eliminated to ease the pilot's cognitive load during high-workload situations. A number of developments have taken place to improve the pilot-display interaction, and this remains an ongoing activity as new technologies and components become available. Examples of these advancements include head-up displays, helmet-mounted displays, and multi-function color displays, which are designed to enhance the pilot's situational awareness and decision-making capabilities.

2. Drawbacks

Cockpit display systems and SoC implementations face several drawbacks. High computational demands for real-time rendering must be balanced with power efficiency, while integration into modern avionics adds complexity due to protocol compatibility. Display technologies have limitations – LCDs struggle with sunlight, OLEDs have a shorter lifespan, and DLPs generate heat. Many display systems are bulky, with weight and space constraints being particularly critical for military aircraft. Power consumption, thermal management, and high costs further challenge adoption. SoCs reduce hardware redundancy, contributing to weight reduction while offering high computational power. However, integrating them into avionics systems increases software maintenance complexity and poses challenges in ensuring reliability.

3. Goal

The goal of this article is to explore and propose a System-on-Chip architecture that can enhance cockpit display systems by reducing hardware redundancy and optimizing weight and space constraints. Over the course of this paper, we will analyze the evolution of display technologies, examine various methods of classifying cockpit displays, and investigate advancements in avionics architectures to showcase the viability and potential benefits of an SoC-based approach for cockpit display systems. By leveraging the integration and efficiency offered by SoCs, this research aims to contribute to the development of more adaptable and sophisticated aviation display systems that can improve pilot situational awareness, system performance, and overall operational safety and efficiency.

4. Cockpit display systems: techniques, technologies, architectures and SoC implementation

4.1 Methods Used in Display Systems

The display systems provide the visual interface between the pilot and the aircraft's systems. Head-up displays (HUD), helmet-mounted displays (HMD), and head-down displays (HDD) are common methods used in cockpit display systems. HUDs and HMDs present critical flight and mission information directly within the pilot's forward field of view, either on the aircraft's windshield or integrated into the pilot's helmet. Head-down displays are mounted in the aircraft's instrument panel, requiring the pilot to look down to view the information. These display methods aim to enhance the pilot's situational awareness by reducing the need to shift visual focus between the external environment and the cockpit instrumentation [2]. Display systems can be categorized into the following, as shown in Fig. 1:

- displayed information type;
- physical positioning of the display;
- display technology.

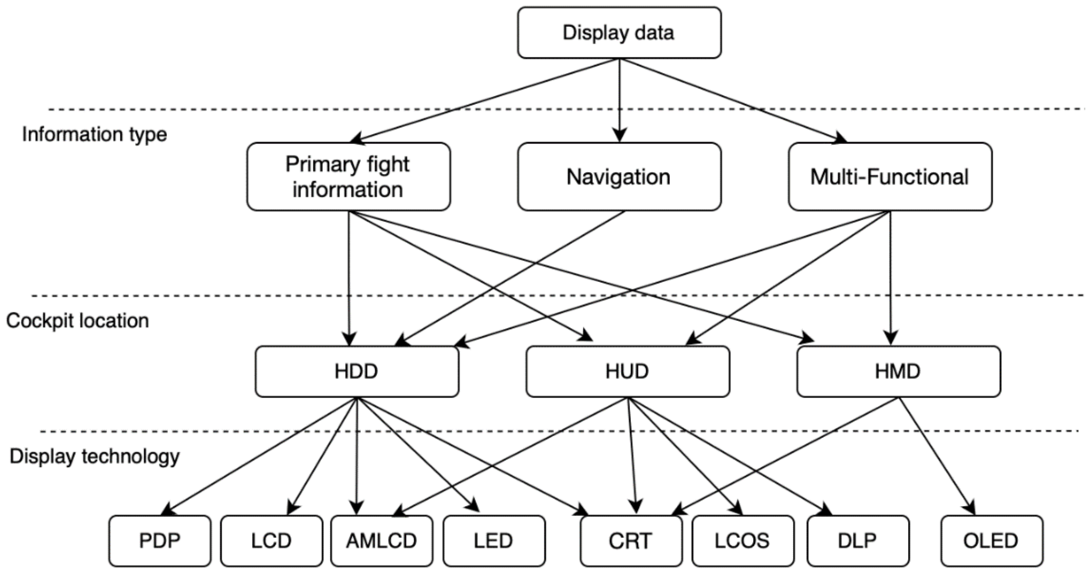

Fig. 1. Display systems classification

Displayed information type. The primary flight data display replaces six traditional electro-mechanical instruments: the altimeter, airspeed indicator, turn and bank indicator, vertical speed indicator, artificial horizon and heading indicator. Navigational information displays the lateral navigation status of the aircraft, including the current position, heading, track, and deviation from the intended course or route. This information is crucial for the pilot to maintain situational awareness and effectively navigate the aircraft to its destination. Multi-function displays are capable of presenting a diverse array of aircraft system data, encompassing engine parameters, communication information, and mission-critical data. Additionally, these displays can serve as primary flight displays and navigation displays, providing pilots with a comprehensive visual interface for monitoring and controlling the aircraft's various systems and operations.

Physical positioning of the display. HUDs and HDDs are statically positioned and fixed into the aircraft's airframe. In contrast, helmet-mounted displays move with the pilot's head orientation, allowing the visual information to be continually aligned with the pilot's line of sight.

Display technology. Display technology has undergone significant advancements in recent years, enabling the development of more capable and flexible cockpit display systems. Traditionally, cockpit displays have utilized cathode ray tubes or mechanical instruments, which have limited functionality. New display technologies opened a way of instrument design.

4.2. Display technologies used in cockpit display systems

Different display technologies are utilized in head-up displays and head-mounted displays, each with unique advantages and disadvantages. Cathode-ray tubes [3] were among the earliest display technologies employed in head-up displays, offering high brightness and contrast. However, they were limited by their size, weight, and high power consumption [4], which drove the need for newer, more efficient display technologies. With advances in display technologies, new types of displays have emerged, offering new capabilities for cockpit display systems. Liquid crystal displays (LCD) have become a popular choice for cockpit displays due to their compact size, low power consumption, and acceptable resolution. However, their limited brightness and contrast can pose a challenge in bright sunlight conditions. High brightness and contrast ratio specifically critical for HUD and HMD, where displays are exposed to a very bright environment. Organic light-emitting diode displays (OLED) offer higher contrast ratios and greater brightness compared to LCDs. However, OLED displays can exhibit reduced lifetime compared to CRT displays, though they still do not provide the same level of brightness as CRT technology. Such display technology suitable for HDD and HMD applications [5]. Active-Matrix Liquid-Crystal Displays (AMLCD), a type of LCD that employs a matrix of thin-film transistors to individually control each pixel, offer improved image quality, faster response times, and higher resolutions compared to passive-matrix LCDs [4]. Liquid Crystal on Silicon (LCoS) displays provide several advantages for use in head-up displays, such as high resolution, good contrast, and a compact size, making them well-suited for modern HUD and HMD applications[4]. However, LCoS displays can suffer from image persistence, which can be a drawback in some situations.

Digital light processing displays (DLP) are known for offering high brightness, excellent contrast, and good color accuracy. These display technologies utilize a digital micromirror device that precisely controls the reflection of light to create the desired image. DLP displays excel in providing high luminance and a wide dynamic range, making them well-suited for use in head-up displays and head-mounted displays operating in bright ambient conditions [6]. However, a potential drawback of DLP displays is that they generate significant heat during operation. This heat generation can require additional cooling systems or design considerations to maintain the display's performance and reliability in the confined environments of aircraft cockpits. DLP displays remain a viable choice for specific HUD and HMD applications where their superior performance attributes prove advantageous [6, 7]. Selecting the appropriate display technology for HUDs and HMDs necessitates carefully weighing factors such as cost, weight, power consumption, resolution, brightness, and contrast to align with the specific requirements and constraints of the aircraft platform. Additionally, the chosen technology should exhibit low maintenance needs to minimize downtime and ensure reliable operation.

4.3 Avionics architecture types

The current state of aviation development features the following avionics architectural designs:

- distributed architecture;
- federated architecture;
- integrated modular avionics architecture;

In the early stages of avionics development, the distributed architecture was the predominant model, featuring autonomous, self-contained systems and instruments, each handling specific localized functions. This approach allowed for a modular and flexible design, where individual components could be easily replaced or updated without affecting the overall system. However, it also led to increased complexity and redundancy, as each system required its own dedicated hardware and software.

The federated architecture represents an evolution from the distributed model, where autonomous systems are combined to reduce the number of computers. This approach includes a concentrator that gathers data from sensors, and central computers that process the signals and provide information to aircraft systems, which then use the data to perform flight functions. This centralized design helped to streamline the avionics architecture and reduce the overall system complexity, improving efficiency and reducing maintenance requirements.

The integrated modular avionics (IMA) architecture overcomes the limitations of the federated approach. It utilizes an open network architecture and a shared hardware platform, providing greater flexibility for modifications and updates. The aircraft's functions are executed through software applications running on a real-time operating system and a common computing platform, allowing for more efficient resource utilization and easier integration of new capabilities. This modular and scalable design enables the development of more advanced and adaptable cockpit display systems, such as head-up displays and head-mounted displays, which can better match the evolving requirements in civil and military aviation. The integrated modular avionics approach offers several advantages for the design and integration of modern cockpit display systems, such as head-up displays and head-mounted displays. By employing a shared computing platform and an open network architecture [8], the IMA architecture allows for more efficient resource utilization and easier integration of new functionalities. This modular and scalable design enables the development of increasingly advanced and adaptable cockpit display systems, which can better match the evolving requirements in both civil and military aviation.

4.4 Implementing Display Processing Unit as System-on-Chip

Historically, avionics display systems have relied on dedicated display processing units to manage the computationally complex tasks of rendering, compositing, and formatting visual information for pilot presentation. The specific computational requirements vary depending on the display type and the amount and complexity of the information being presented. Head-down display units, for instance, tend to have simpler rendering requirements focused on the presentation of navigation, flight, and systems information. In contrast, more advanced cockpit display systems like head-up displays and helmet-mounted displays require additional capabilities for real-time integration of dynamic flight, sensor, and other mission-related data. With advancements in semiconductor technology, it is now possible to integrate the necessary display processing functions into a system-on-chip (SoC), leveraging open network architecture of the integrated modular avionics design, to provide a more compact, power-efficient, and cost-effective solution for modern avionics application.

For a simple head-down display, which can represents primary flight instrumentation, engine and system indications, basic navigation, the display processing unit can be implemented as a single bus system-on-chip, which is capable of composite 2D rendering of symbology and raster imagery, typically sourced from distributed avionics data buses, as shown in Fig. 2.

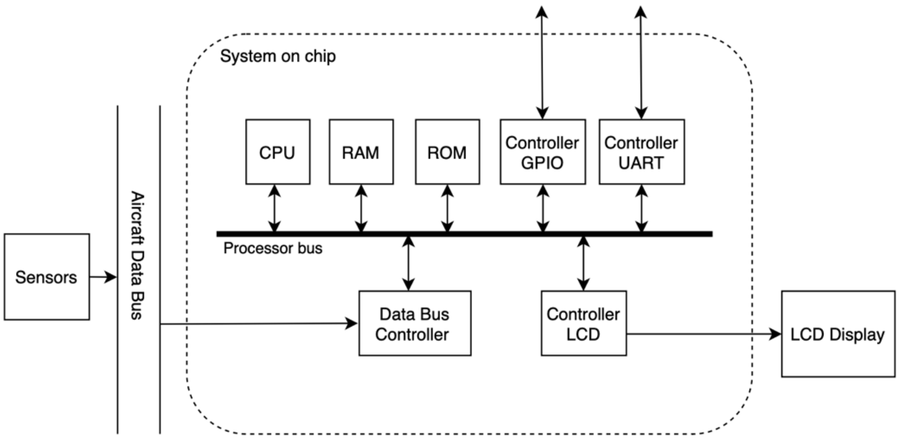

Fig. 2. Single bus system-on-chip

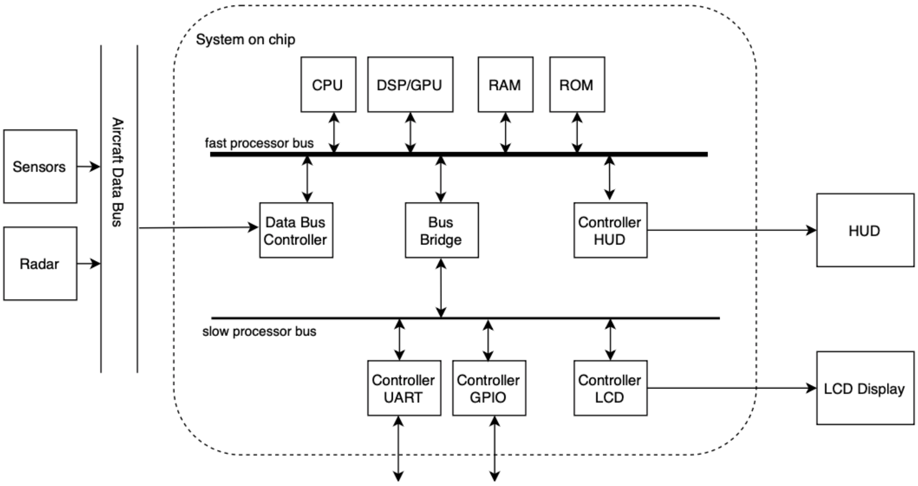

Fig. 3. Dual bus system-on-chip

For receiving primary flight information from sensor and other aircraft systems, the display processing unit features a data bus controller that ingests avionics data protocols (ARINC 429, CAN, MIL-STD-1553) [4, 9]. Additionally, the display processing unit includes standard controllers for UART and GPIO, which can serve as inputs for button control or a standalone control panel.

The program is stored in read-only memory, and the data is stored in random-access memory. The central processing unit performs calculations according to carrying out the tasks of rendering, compositing, and formatting visual information based on the input from sensors, systems, and control inputs. The single bus system-on-chip design has limited capability and complexity, yet it effectively meets the requirements for basic head-down display applications. For more advanced display systems like head-up displays, which also support information duplication onto head-down displays, the architectural complexity of the display processing unit increases to accommodate the higher computational demands and more diverse input sources. In such cases, a system-on-chip with two busses [10] can be a more appropriate solution as shown in Fig. 3. It provides additional flexibility and performance to handle the increased processing requirements.

The dual bus system-on-chip display processing unit features a fast processor bus to which the processor, RAM, ROM, and the HUD controller are all connected. Additionally, the display processing unit now accepts radar data as an input, along with the aircraft sensor information. The second bus (slow processing bus) which operates on slower speeds is used for UART, GPIO and LCD controllers. The dual bus architecture enables the display processing unit to efficiently handle the increased workload of rendering complex HUD symbology, overlaying sensor data, and compositing the information for simultaneous presentation on the HUD and head-down displays.

For even more sophisticated display systems with more input sources, data fusion requirements, and advanced rendering needs, the display processing unit architecture can be further enhanced using multiple bus topologies and GPU or DSP coprocessors, as shown on Fig. 4.

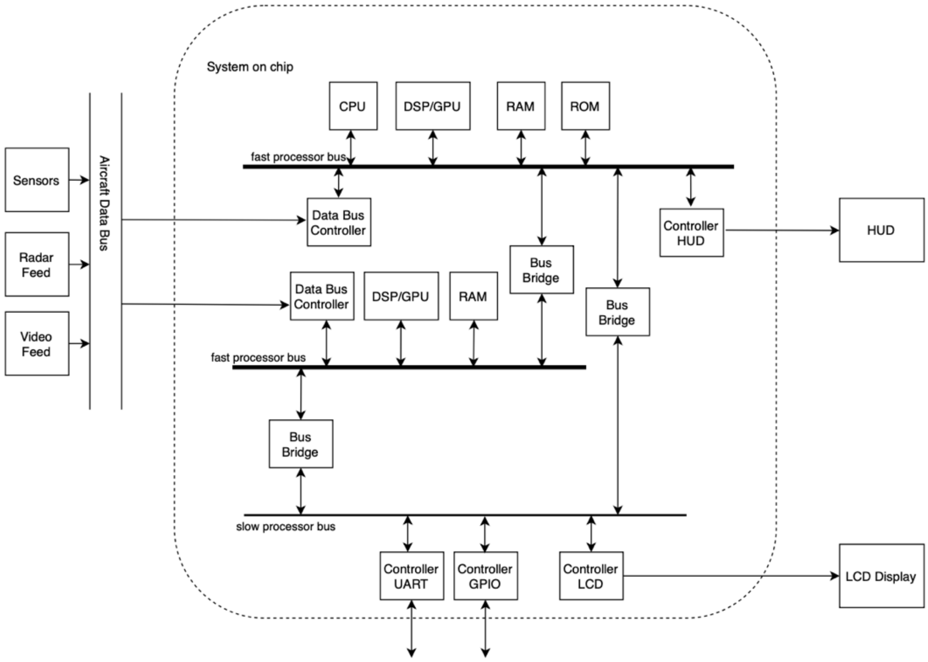

Fig. 4. Triple bus system-on-chip

The triple bus system-on-chip display processing unit features an additional video input source, which in combination with sensor and radar information enables advanced data fusion. Two high-speed buses are dedicated to parallel processing of sensor data fusion and rendering complex head-up display symbology, while a slower peripheral bus manages control and interface functions. The incorporation of a dedicated graphics processing unit or digital signal processor allows the display processing unit to efficiently handle the increased computational workload, maintain real-time performance, and deliver the advanced visualization capabilities required by the most sophisticated cockpit displays. The architectural advancements, enabled by the integrated modular avionics framework and system-on-chip technology, have facilitated the evolution of increasingly sophisticated avionics display systems to meet the growing demands of modern aviation.

4.5. Analysis of the Proposed System-on-Chip Architectural Designs

The single bus system-on-chip architecture can be leveraged to implement basic electronic flight instrument systems, which are commonly built as head-down displays providing core flight information. Typically, such systems have simpler rendering requirements focused on presenting navigation, flight, and systems information. Electronic flight instrument systems that deliver fundamental flight data, such as navigation, aircraft performance, and systems information, are widely utilized across a variety of aircraft platforms [4]. These basic systems are integrated into experimental, general aviation, commercial and military aircraft, playing a crucial role in providing pilots with essential flight information, which is vital for maintaining aviation safety and efficiency.

The dual bus system-on-chip architecture is well-suited for advanced cockpit display systems with increased graphical demands. The integration of a dedicated graphics processing unit or digital signal processor enables the rendering of more complex symbology, the presentation of multiple data streams, and the integration of sensor inputs. These advanced cockpit display systems are commonly found in sophisticated primary flight displays and multi-function displays. The enhanced capabilities of the system-on-chip architecture empower the display processing unit to effectively manage the elevated computational requirements associated with the advanced visualization features and the ability to provide multiple output sources. This type of display processing unit architecture can be employed in both commercial and military aircraft to support the increased computational demands.

The triple bus system-on-chip architecture, with its dedicated high-speed buses for sensor data fusion and rendering, combined with a graphics processing unit or digital signal processor, allows for the construction of the most advanced cockpit display systems. Leveraging separate high-speed buses improves the efficiency of parallel processing operations and enables the integration of complex data fusion algorithms and advanced visualization capabilities. This architectural approach provides the necessary computational power and flexibility to handle the increasing complexity and data requirements of modern cockpit display systems, which are crucial for enhancing aviation safety and efficiency in both civil and military aviation.

5. Conclusions

The article provides a comprehensive analysis and classification of methods employed in cockpit display systems, emphasizing their crucial role in aviation safety and efficiency. It highlights the technological evolution of these systems and its impact on both civil and military aviation. The research explores the advances in display technologies, such as the transition from CRT to LCD, AMLCD, OLED, and DLP, discussing their respective pros and cons. The article also explores the classification of cockpit displays based on information type, physical positioning, and display technology. Additionally, the research examines the advancements in avionics architectures, particularly the integration of display processing units as system-on-chip designs. The article also proposes three implementation options for the display processing unit architecture to accommodate increasingly sophisticated cockpit display systems. These options include a single bus system-on-chip design for basic head-down display applications, a dual bus system-on-chip design for more advanced display systems like head-up displays, and a triple bus system-on-chip design for the most sophisticated cockpit displays with multiple input sources, data fusion requirements, and advanced rendering needs. The prospects for further development of cockpit display systems based on systems-on-a-chip are outlined, with the prospect of improving their characteristics, expanding their functionality, and reducing the overall dimensions and power consumption of such systems.

Gratitude

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Conflict of Interest

The authors state that there are no financial orother potential conflicts regarding this work.

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