# Assessing the Prevalence and Future of I2C Devices in Commercial Aircraft's Embedded Systems

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**Abstract**
**Serial communication technologies such as I2C (Inter-Integrated Circuit) and SPI (Serial Peripheral Interface) have long been integral to avionics systems for data transfer between components, such as sensors, controllers, and peripheral devices. As avionics systems evolve and demand higher performance, older technologies like I2C and SPI face bandwidth, power efficiency, and scalability limitations. MIPI has developed the new I3C (Improved Inter-Integrated Circuit) standard to address these challenges. I3C is built with I2C fundamentals in mind while bringing several advanced features that resolve some of the challenges faced by I2C. Thus, offering a more efficient and scalable solution for modern avionics. This paper investigates some of these existing serial communication protocols, discusses how they are used in aviation, discusses their drawbacks, and discusses how I3C can address some of them. It will also discuss the challenges of adopting this new I3C protocol in aviation.**

**Keywords: Embedded systems, I2C, I3C, SPI, MIPI, Aerospace Systems**

## I. INTRODUCTION

Serial communication protocols in avionics have been critical in enabling the operation of various subsystems, such as flight control, navigation, environmental systems, and sensor data acquisition. Over time, I2C and SPI have become ubiquitous for serial communication between microcontrollers, sensors, and other embedded components due to their simplicity and low cost. According to estimates, I2C devices cover up to 30-50 percent of overall embedded communication interfaces in modern commercial aircraft.

However, as avionics systems have become more complex and data-intensive, traditional serial protocols have begun to exhibit significant limitations. These include bandwidth constraints, power consumption concerns, and difficulties supporting many devices on a single bus. The advent of I3C, a more advanced version of I2C, offers potential solutions to many of these challenges.

This paper focuses on:

- The limitations of existing serial protocols (I2C and SPI) in avionics systems.
- How I3C addresses some of these problems.
- The challenges of adopting I3C for future avionics designs.

## II. Overview of Serial Communication Protocols in Avionics:

Avionics systems rely on serial communication protocols to exchange important data between components such as sensors, displays, navigation, and control systems. The choice boils down to requirements for each of the applications. This can vary based on speed, reliability, cost efficiency, and power consumption.

In avionics systems, serial communication protocols enable efficient and reliable data exchange between various components, such as sensors, displays, control systems, and navigation equipment. Different serial protocols are employed based on the requirements of specific applications, including data speed, reliability, distance, and power consumption.

In recent years, the aviation industry has witnessed a growing interest in transitioning from I2C and SPI to I3C (Improved Inter-Integrated Circuit), a next-generation protocol developed by MIPI designed to overcome the limitations associated with its predecessors. Migration to I3C is needed for enhanced performance, bandwidth, and reduced power profile in modern aviation systems. Understanding the factors that drive this migration and the benefits it offers represents a critical area of study within avionics communication protocols. To understand this, we need to look at all the characteristics of existing serial communication protocols used in aviation systems. Table 1 lists the most used serial communication protocols in avionics.

| Protocol Type | Speed | Communication Type | Bus Type | Avionics Application | Pros | Cons |
|---|---|---|---|---|---|---|
| I2C | Up to 3.4 Mbps (High Speed) | Half-Duplex (Master-Slave) | Two-wire (SDA, SCL) | Sensors (e.g., temperature, pressure), displays, actuators | Simple, low power, low cost, multi-device support | Limited range (few meters), slower speed, not suitable for high-speed or long-distance applications |
| SPI | Up to 10 Mbps or more | Full-Duplex (Master-Slave) | Four-wire (MISO, MOSI, SCK, SS) | High-speed sensors, memory, communication modules | Requires more wiring, shorter range, higher power consumption than I2C | Requires more wiring, shorter range, higher power consumption than I2C |
| CAN | Up to 1 Mbps | Multi-Master, Message-Based | Two-wire differential | Flight control systems, engine control, avionics subsystems | High reliability, fault tolerance, suitable for noisy environments, long distances | Limited data rate compared to Ethernet, more complex than I2C or SPI |
| RS232/RS-422/RS485 | Up to 1 Mbps (RS-232), higher for RS-422/RS-485 | Point-to-Point or multi-drop | Single-ended or differential | Ground support equipment, communication interfaces | Simple and widely supported, long-distance (RS-422/RS-485) | Limited data rate, not suited for high-speed avionics, older technology |
| MIL-STD-1553 | 1 Mbps | Dual-Redundant Bus, Message-Based | Two-wire (differential) | Military avionics, mission-critical systems (navigation, radar, weapon systems) | High fault tolerance, real-time communication, redundancy | Lower data rate, high cost, complex compared to newer protocols |
| ARIC 429 | 12.5 or 100 kbps | One-Way (Unidirectional) | Single-ended | Flight data acquisition, autopilot, radar, navigation systems | High reliability, error detection, robust against interference | One-way communication, slower data rates, rigid and less flexible than other protocols |

**Table 1: Serial communication protocols used in aviation industry**

## III. Focus ON I2C AND SPI

This section focuses on I2C and SPI as representative serial communication protocols in avionics, along with why and how they are currently used and their associated challenges.

### A. I2C (Inter-Integrated Circuit) in Avionics:

I2C is a widely used serial communication protocol that connects low-speed devices, such as sensors, to microcontrollers and processors in embedded systems. It operates over a two-wire bus (SDA for data and SCL for clock) and supports multiple devices identified by a unique address [5].

Pros:

- Straightforward to implement with minimal wiring.
- It supports multiple devices on a single bus with master-slave architecture.
- Low cost and widely available.

Cons:

- Limited Bandwidth: The typical data rate of I2C is limited to 100 kbps or 400 kbps (with higher-speed modes of up to 3.4 Mbps, but still relatively slow for modern applications).
- Bus Congestion: As the number of devices on the bus increases, signal integrity can degrade, and bus congestion becomes a concern, affecting performance.
- Short Communication Range: I2C is unsuitable for long-distance communication and is often needed in complex avionics systems.
- Limited Address Space: The 7-bit addressing scheme in I2C limits the maximum number of devices to 127, which can be restrictive in larger systems.

Why I2C is Common in Aircraft:

I2C is used for the specific tasks in commercial aircraft because:

- Low-Speed Communication: I2C is ideal for low-speed devices such as sensors, actuators, and specific power management components, which are common in avionics.
- Simple Wiring: I2C's two-wire bus (SDA and SCL) simplifies the wiring, a significant advantage in space-constrained environments like aircraft.
- Multi-device Communication: I2C allows multiple devices to share a single bus, making it ideal for integrating various subsystems within an aircraft
- Cost-Effective: I2C's simplicity and minimal hardware requirements make it a cost-effective option, which is crucial for mass-produced commercial aircraft.

Common Applications of I2C in Aircraft Systems:

- Sensors: I2C is widely used for low-speed sensors in aircraft, such as temperature, pressure, and humidity sensors, as well as accelerometers and gyroscopes in some cases.
- Displays and Indicators: I2C is commonly used in cockpit displays, LED indicators, and control panels.
- Flight Management Systems (FMS): I2C may be used for low-speed communication between subsystems in the FMS, such as control units.

- Power Management: I2C is often used in power supply systems to monitor voltage, current, and battery health.
- Actuators and Control Systems: In non-critical applications, control systems use I2C devices such as servo motors, valves, and control panels.

B. SPI (Serial Peripheral Interface) in Avionics:

Serial peripheral interface (SPI) is one of the most commonly used serial protocols for inter-chip and intrachip low/medium-speed data-stream transfers. It communicates between a microcontroller and devices like external EEPROMs, DACs, ADCs, etc. [1,3,4].

Pros:

- Higher Speed: SPI can achieve higher data rates than I2C
- Full-Duplex Communication: Unlike I2C, SPI permits full-duplex communication, meaning simultaneously sending and receiving data

Cons:

- Bus Complexity: SPI requires more wires (at least 4: MISO, MOSI, SCK, and SS), making it less efficient in systems with many peripherals.
- Device Addressing: Each device on the bus requires a separate chip select (CS) line, which can lead to large numbers of control lines in systems with multiple devices[4].
- No Multimaster Support: Unlike I2C, SPI does not support multi-master configurations, limiting flexibility in certain use cases.
- Limited Range: Like I2C, SPI is not designed for long-range communication and is subject to signal degradation over long distances.

Why SPI is Common in Aircraft:

I2C is used for the specific tasks in commercial aircraft because:

- High Speed Data Transfer: Higher data transfer rates than I2C
- Full Duplex Communication: Allows simultaneous send and receive. This can be effective in aircrafts for monitoring and controlling actuators continously
- Scalability: Its simple bus architecture can be extended to suit systems ranging from basic sensor interfaces to large, complex data acquisition systems.
- Low Communication Latency: Since its synchronous protocol, it has less communication latency which is crucial in avionics for real time feedback from sensors
- Flexibility: SPI can support multiple slave devices through the use of multiple chip-select lines[4]. This flexibility is especially beneficial in aircraft where multiple sensors, memory devices, or actuators must communicate with a central processor without overwhelming the bus.

Common Applications of SPI in Aircraft Systems:

Below are some typical applications of SPI in aircraft systems.

- Sensor Interfaces: Used to interface with high speed sensors for pressure, temperature and accelerometer

- Memory Devices:SPI is frequently used to interface with non-volatile memory devices such as flash memory to store flight configurations and EEPROM to store calibration data of critical components. Quick reads/writes to memory are crucial in aviation systems.
- Display Systems:SPI frequently controls displays such as cockpit instrument panels, LCD screens, and LED-based systems. Fast, high-bandwidth communication is needed to update the real-time flight data.
- Actuators:SPI is used to control actuators, especially in systems that need precise control, such as throttle position sensors.
- Communication Modules:SPI interfaces with various communication modules, such as Wi-Fi, Bluetooth, GPS, and satellite, that manage data transfer between avionics subsystems.
- Data Acquisition Systems:Many modern avionics systems use SPI to communicate with data acquisition modules that gather sensor data, environmental readings, or engine performance metrics for analysis. These systems require the high-speed data throughput that SPI provides.

C. Challenges of I2C and SPI in Avionics Systems:

- Bandwidth and Speed LimitationsWhile adequate for low-speed applications, both I2C and SPI are increasingly inadequate for the high-throughput data requirements of modern avionics. Modern avionics systems incorporate high-definition sensors, multimedia data streams, and complex control algorithms that demand significantly higher data transfer rates. The lower data rates provided by I2C can impede real-time communication between critical avionics components. On the other hand, SPI provides faster speeds but faces challenges with scalability and maintaining signal integrity when multiple devices are connected.

- Power ConsumptionAvionics systems often face strict power constraints, especially those used in satellites, drones, or uncrewed aerial vehicles (UAVs). Both I2C and SPI have limitations when it comes to power efficiency. I2C is more power-efficient due to its lower data rates and more straightforward bus structure. In contrast, while offering faster communication, SPI consumes more power because of its higher clock speeds and the additional wires required, resulting in higher standby currents. As a result, both protocols can present challenges in long-duration missions or for low-power devices, such as sensor nodes or battery-powered systems, where minimizing energy consumption is critical.

- Bus Congestion and ScalabilityAs avionics systems become increasingly integrated, the number of connected devices has grown significantly, presenting scalability challenges for I2C and SPI. I2C can become congested as more devices are added to the bus, with a limited number of available addresses and the potential for bus contention, which reduces communication efficiency. Meanwhile, SPI also struggles with scalability because each additional device requires a unique chip-select line, making managing large systems with many devices challenging. These limitations become more pronounced as the complexity of avionics systems continues to increase.

- Signal Integrity and DistanceI2C is typically limited to short-distance communication within the same PCB or enclosure. Its use of open-drain outputs can make it more susceptible to noise, particularly in aircraft's electrically noisy environments. While SPI offers faster data transfer rates than I2C, it faces similar distance limitations. The risk of adding more wires to connect multiple devices is signal degradation over long distances, making both protocols less suitable for long-range communication within complex avionics systems.

## IV. A USE CASE STUDY:ADAPTING I3C FOR AVIONICS APPLICATION

A. What is I3C:

I3C (Improved Inter-Integrated Circuit) is a protocol developed by the Mobile Industry Processor Interface (MIPI) Alliance. It is primarily used for connecting sensors in mobile System on Chips (SoCs). The key advantages of I3C include higher speed and a reduced pin count compared to traditional interfaces. Additionally, the I3C protocol is backward compatible with I2C devices, ensuring ease of integration with existing systems [2].

B. How I3C can Address the Challenges of I2C and SPI in Avionics:

- Higher Bandwidth and SpeedWith speeds reaching 12.5 Mbps in standard mode and 33.4 Mbps in high-speed mode [6], i3c can handle much larger volumes of data, which is especially important for modern avionics systems that rely on high-performance sensors and video systems. I3C also permits devices to adjust their data rates dynamically, which means the system can adapt based on the needs of each application or even environmental conditions.
- Power EfficiencyI3C is designed to be power-efficient, which is critical for avionics systems with strict power budgets, like those in UAVs or satellite applications. The low-power mode makes it ideal for battery-powered sensors, while its efficient signaling and fewer pin requirements help reduce power consumption during idle states. This makes I3C a great fit for systems where every bit of power counts.
- Improved ScalabilityOne of I3C's biggest advantages is its ability to scale easily, something both I2C and SPI struggle with. I3C supports dynamic addressing, meaning you can connect hundreds of devices on the same bus without running into the addressing limits of I2C. Plus, its multi-master capability removes the need for separate chip-select lines, which reduces wiring complexity and makes it easier to manage large systems—perfect for avionics applications that keep getting more complex.
- Better Signal Integrity and DistanceI3C improves signal integrity over longer distances, which is a common challenge for both I2C and SPI. It uses differential signaling, which reduces the impact of noise and helps maintain reliable communication, even in the noisy electromagnetic environments typical of aircraft.
- Backward CompatibilityOne of the standout features of I3C is its backward compatibility with I2C. This means avionics systems can upgrade to I3C without needing to completely replace their existing infrastructure. Devices that use I2C can continue to work while taking advantage of the new features and improvements I3C offers, allowing for a smoother and more gradual transition to more advanced systems.

## V. CONCLUSION

I2C, SPI, and other serial protocols have been essential for avionics systems over the years. However, with modern avionics continuing to expand with newer use cases like autonomous flight, these traditional protocols face significant challenges which we listed in this paper. We also looked at a possible solution, which is I3C that tackles some of these challenges like limited bandwidth, high power consumption, scalability, and signal integrity. With faster data transfer rates, better power efficiency, and the ability to handle larger systems more efficiently promised by MIPI, I3C is potentially a good fit to meet the growing needs of avionics. Plus, its compatibility with I2C ensures a smooth transition, making it an ideal choice for the future of embedded communication in aircraft.

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