Application Note

Analog Multiplexer Applications in SPI, QSPI, and OSPI Automotive, Industrial, and Data Center Systems

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ABSTRACT

Data centers, automotive Advanced Driver Assistance Systems (ADAS), and industrial automation are rapidly growing markets which require high speed and low-latency communication. Serial Peripheral Interface (SPI) and its variants Quad-SPI (QSPI) and Octal-SPI (OSPI) enable these technologies with high data-rates through multiple data lines and clock-data synchronization. However, multi-peripheral systems containing sensors, controls, and memory-access networks are often limited by available GPIOs on MCU's and board-size constraints, as well as high cost associated with ADCs.

This application note explores current industry use cases for SPI, QSPI, and OSPI with analog multiplexer solutions to eliminate GPIO and ADC constraints for high-density SPI systems.

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Trademarks

1 Introduction

As modern systems become increasingly data-intensive and computationally heavy, there is a growing need for faster speed communication. SPI has become a popular protocol across many industries due to its ability to provide continuous streams of data, supporting faster data-rates, and allowing full duplex communication between peripheral ICs and a controller. While standard SPI typically uses two data lines, Quad-SPI (QSPI) and Octo-SPI (OSPI) use four and eight lines respectively, significantly increasing data throughput. SPI has many market applications in data centers, automotive, and industrial systems. To support high-density and multi-peripheral SPI systems, multiplexers can overcome GPIO pin and ADC limitations by switching SPI buses, signals, or control pins to reduce complexity, cost, and board size.

2 Protocols Overview

SPI

Serial Peripheral Interface is a serial communication protocol with a simple architecture consisting of a main controller and one or more peripheral devices.

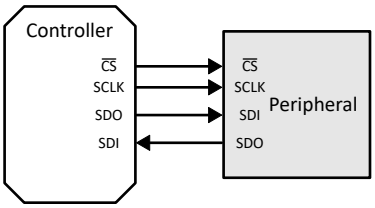

Figure 2-1. Standard 4-Wire SPI

The controller generates the clock signal (SCLK) and chip-select () signal to enable or disable specific peripheral devices. Standard SPI communication uses two unidirectional data lines, Send Data Out (SDO) and Send Data In (SDI), allowing the controller and peripheral ICs to simultaneously write and read data, supporting full-duplex communication. 3-wire SPI is an alternative that utilizes only one bidirectional data line to both transmit and receive data.

Signal Name	Usage
SDO	Sending data out to the target
SDI	Receiving data in from the source
SCLK (Serial Clock)	Generated by the controller to synchronize data transfer
$\overline{CS}$ (Chip Select)	Enables communication when pulled low

A primary advantage of SPI over other protocols is faster and more precise data transfer. Data is synchronized with a clock signal, enabling high-frequency communication with accurate timing for reads and writes. SPI's continuous data streaming also eliminates the need for interrupts or complex addressing schemes, reducing latency.

In data centers, due to the large amount of data stored, require high-speed data access as well as system monitors for environmental and electrical conditions. SPI can be used to interface between temperature, pressure, and voltage sensors. SPI communication reduces latency between the sensors and controllers, minimizing the potential for system damage or failure. It is also relevant in automotive ADAS systems, which rely on real-time monitoring and sensing with cameras, radar, lidar, and infrared sensors, where low latency is essential to ensure rapid reaction time.

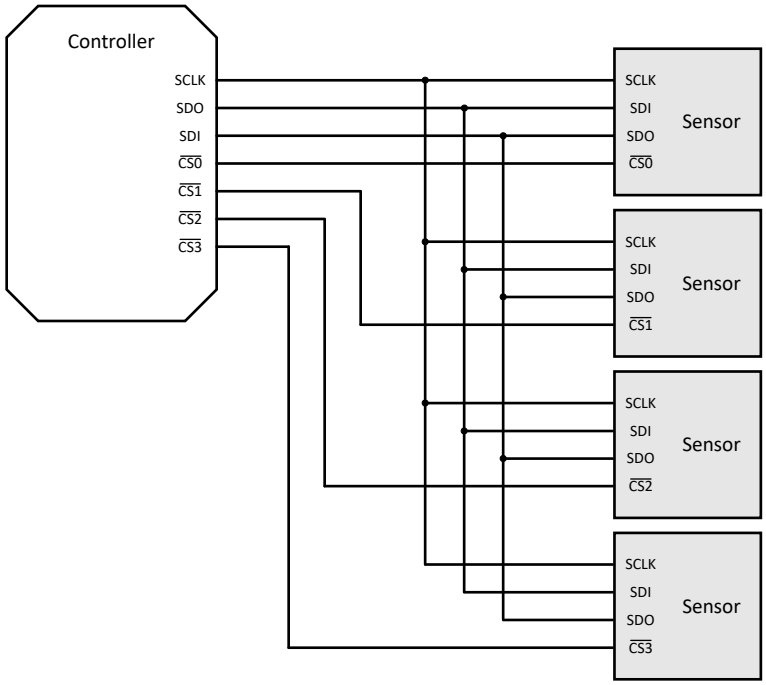

Figure 2-2. Standard 2-Wire SPI Communication with Multiple Peripherals

Since each device requires an individual chip-select line, SPI poses a potential challenge for high-density systems with many peripheral devices and a limited number of GPIO pins. Current solutions tend to use GPIO expanders or larger MCUs, increasing BOM count and solution size.

To overcome this, a multiplexer, such as the TMUX1204 (4:1), can switch one chip-select line between multiple peripheral devices. As shown in Figure 3 below, it reduces four pins to only one GPIO, with a fast transition time of 14 ns and size as small as 2.5 mm ^{2} . For larger systems, the TMUX1208 (8:1) has identical switching time and electrical characteristics but can replace up to eight pins.

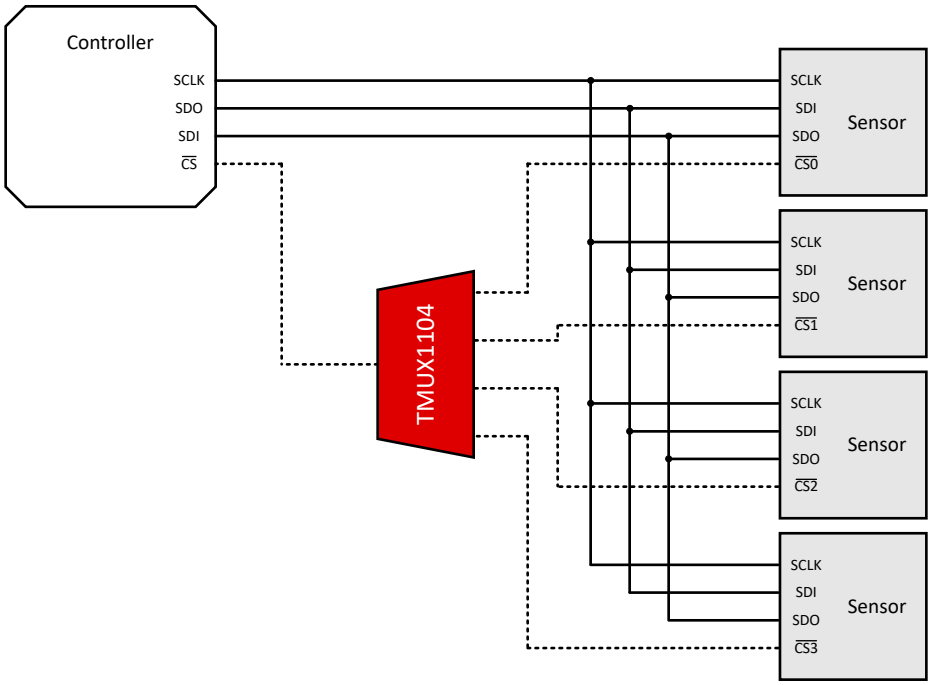

Figure 2-3. TMUX1104 Muxing Chip Select Signal

Another high-density solution multiplexers provide is reducing ADC count in industrial or data center sensor networks system designs. When communicating with sensors such as voltage, pressure, and temperature sensors, an individual ADC for each signal leads to a significant increase in area and cost. Multiplexers can switch several analog outputs to a single ADC, with a 16:1 multiplexer, such the precision multiplexer MUX506, effectively replacing 16 individual ADCs.

Precision multiplexers are rated with low charge injection and leakage current to ensure signal integrity. This is especially relevant in data center applications for cooling systems and electrical monitors to ensure proper operation. Industrial systems also rely on many sensors for motor control, factory automation, and robotics. These require pressure and electrical sensing for packaging, manufacturing, and equipment operation. Figure 4 below illustrates a single-wire SPI system, using the TMUX1104 (4:1) to switch between three sensors, utilizing only one ADC. When not using all the channels, unused pins can be tied to ground to avoid potential noise or crosstalk.

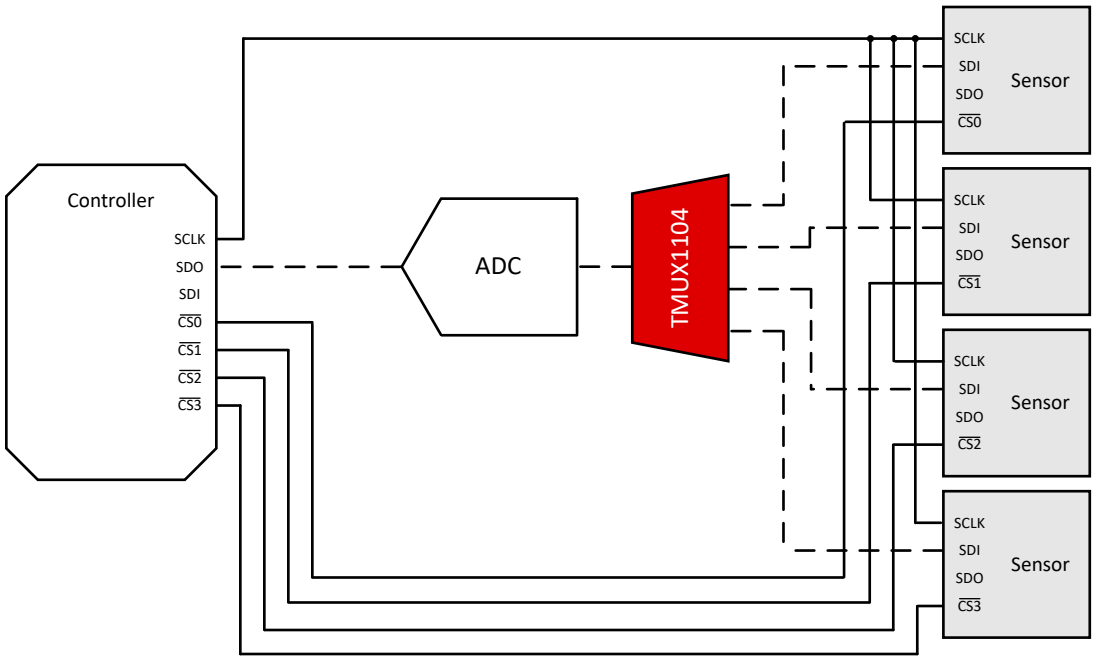

Figure 2-4. TMUX1104 Switching Data Lines to Reduce ADCs

QSPI

Quad-SPI follows a very similar protocol to standard SPI but achieves enhanced data rates with four half-duplex data lines. The additional data lines allow up to four times the amount of data to be transferred, effectively quadrupling the date-rate of SPI. QSPI is particularly applicable in data centers, serving as the communication interface between the main processors and external flash memory, which store FPGA firmware and BIOS system images. QSPI enables faster boot times and system startups compared to standard SPI. It also has low-latency applications in the automotive industry for real-time control and monitoring, such as infotainment systems and body module controls.

Although QSPI improves system throughput, it also introduces system limitations by requiring additional I/O pins, increasing both cost and area to accommodate signal routing and pin requirements. However, by multiplexing a SPI bus, one set of GPIO pins can enable communication between the main controller and multiple flash chips, as shown below in Figure 5. With high bandwidth, low capacitance, and excellent isolation, the TMUXL27518 (2:1 6-ch) is designed for expanding multimedia card host devices to multiple peripherals. It provides switching between primary and backup flash in the event of an outage or data corruption, ensuring consistent data accessibility under emergency conditions while providing a space and cost-effective solution.

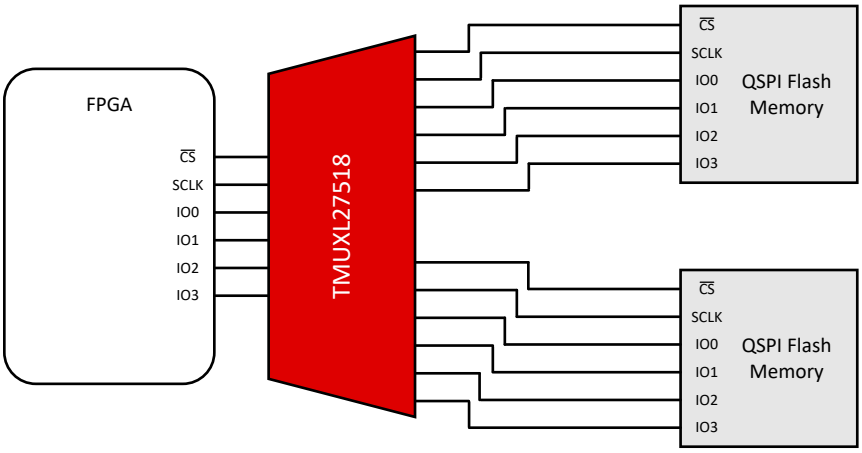

Figure 2-5. Multiplexer Switching Between QSPI Flash Memories

OSPI

For applications requiring more data throughput, Octal-SPI provides eight half-duplex data lines, doubling the data-rate of QSPI. While OSPI use cases are similar to QSPI, it is typically found in designs requiring higher throughput and faster response times, such as MCU or FPGA systems in data or high-computing centers. OSPI is also growing in popularity with automotive applications due to its high data-rate signaling. Current uses include infotainment systems requiring high-resolution graphics and rapid stored-memory access, as well as ADAS systems for autonomous driving control and sensing. Data-intensive system backups also utilize OSPI for memory bank and fail-safe boot selection. Fail-safe protection is essential to ensure safety and reliability for both data centers and ADAS systems, which must recover quickly in the event of memory corruption or power loss.

Like QSPI, OSPI pin requirements can pose a challenge for high density applications. Signal multiplexing allows systems to efficiently switch between primary and backup selections for memory or power, reducing both GPIO count and system area, as shown in Figure 6. As similarly used for QSPI bus multiplexing, two SN3257-Q1 (2:1, 4-ch) muxes, can be used to switch between two OSPI memories.

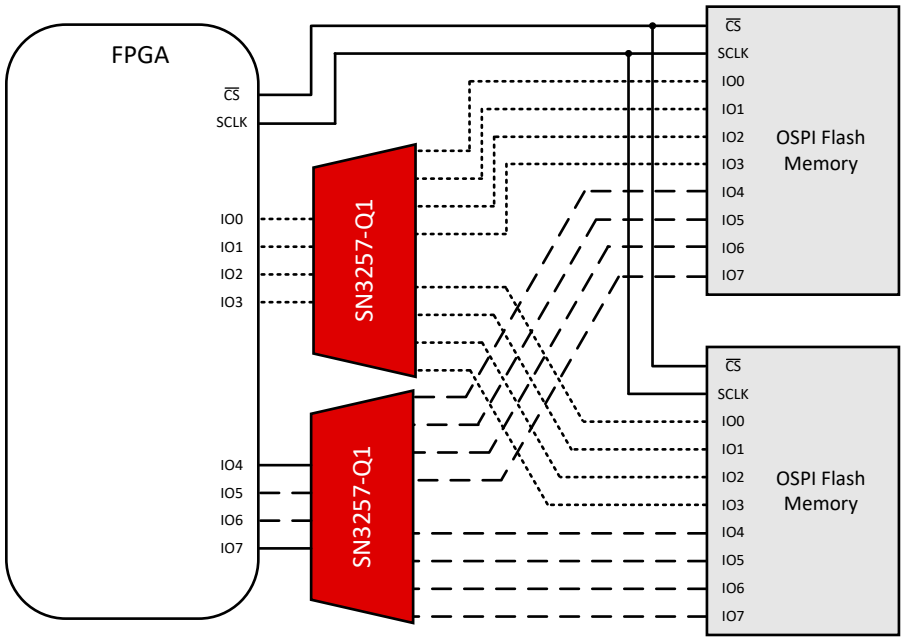

Figure 2-6. Multiplexers Switching Between OSPI Flash Memories

3 Summary

SPI provides high-speed, low-latency communication for sensing, control, and memory-access systems across a range of industrial, automotive, and data center applications. While typical uses of SPI, QSPI, and OSPI differ, their applications often overlap and are chosen for specific data-rate and system requirements. Multiplexers can overcome common limitations encountered by SPI systems during implementation, such as limited GPIO amount on MCUs and high ADC count. By switching SPI signals lines, multiplexers provide a simple, low-cost and compact solution for high-density and high-speed SPI applications. Recommendations for specific use cases can be found in Table 3-1.

Table 3-1. Suggested Devices

Suggested Device	Configuration	Channel Count	Protocol	Application	Supply Voltage	Leakage Current IS(ON)	CON	Bandwidth
TMUX1204	4:1	1	SPI, QSPI, OSPI	I/O expansion for Chip Select lines with low-power and Break-Before-Make Switching	1.08V - 5.5V	200nA	42pF	125MHz
TMUX1208	8:1	1					85pF	65MHz
TMUX1209	4:1	2					42pF	125MHz
MUX506	16:1	1		ADC precision switching with low leakage current and low charge injections	±5V – ±18V 10V – 36V	0.02nA	13.5pF	500MHz
MUX507	8:1	2					8.7pF	
TMUX1104	4:1	1			1.08V - 5.5V	0.01nA	35pF	155MHz
TMUX1574	2:1	4	QSPI, OSPI	Flash memory reading with high bandwidth	1.5V - 5.5V	0.01nA	7.5pF	2GHz
TS3A27518E	2:1	6			1.65V - 3.6V	30nA	21.5pF	240MHz
TMUXL27518	2:1	6			1.08V - 1.95V	20nA	12pF	600MHz
TS3A27518E-Q1	2:1	6		Automotive-qualified flash memory	1.65V - 3.6V	30nA	21.5pF	240MHz
SN3257-Q1	2:1	4			1.5V - 5.5V	30nA	8pF	2GHz
TMUX1208-Q1	8:1	1	SPI	Automotive-qualified SPI	1.08V - 5.5V	200nA	85pF	65MHz

4 References

- Texas Instruments, *From Bottleneck to Breakthrough: QSPI Optimization in Data Centers with TXB0604/TXB0606L*, application brief.
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- Texas Instruments, *Using SPI Controlled MUX To Increase Channel Density*, application note.
- Texas Instruments, *Scalable 16-48 Bit GPIO Expander for Modern Automotive*, application note.
- Texas Instruments, *Throughput Characterization of OSPI and QSPI Serial*, application note.

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