Application Note

SPI Communication Issues in Wearable Applications and Designs Using AFE4xxx in Smart Watch Applications

TEXAS INSTRUMENTS

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ABSTRACT

The trend in wearable devices is toward low-power, ultra-small form factors, and the integration of diverse functions into a single application smartwatch. Smartwatches are the most widely known application, but the reach of smartwatches is expanding to include rings, bands, earphones, and more. Wearable designs often incorporate a variety of communication protocols, including Bluetooth®, LTE, 5G, SPI, and I2C, within a small device area. Consequently, signal interference can occur at any time within the application, and effectively managing this interference is a crucial skill and expertise. This application report demonstrates communication issues (particularly SPI) that can arise in increasingly smaller and more complex wearable designs, and how to identify and resolve causes.

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1 Introduction

The AFE4xxx family is a versatile signal acquisition system that supports acquiring PPG, EDA, ECG, and bioimpedance signals. A PPG signal chain comprises a current driver for LEDs and a receiver that senses the signal from PDs. An ECG receiver with a right leg drive (RLD) can acquire a single-lead ECG from a pair of electrodes. An impedance measurement signal chain with integrated excitation and sense can be used for applications such as BIA, EDA, and impedance spectroscopy. The outputs of the various signal chains are digitized by a common ADC and stored in a FIFO, which can be read out using an SPI interface.

In increasingly compact wearable devices, the signal integrity (SI) of each signal is a critical factor. Recent wearable devices are susceptible to noise because the devices incorporate various communication modules, such as Bluetooth, Wi-Fi, and LTE, in addition to internal wired communication. As a result, minimizing the coupling and noise levels that can occur within the application to prevent malfunctions is crucial. This report describes countermeasures for SPI communication issues and the situations that must be considered during product design to mitigate the impact of such noise.

Figure 1-1 shows the basic SPI communication pins and connections. SPI 4-wire communication consists of four communication lines: SCLK, SDIN, SEN, and SDOUT. Furthermore, separate pull-up and down is not required, and direct connections between the master and slave are required.

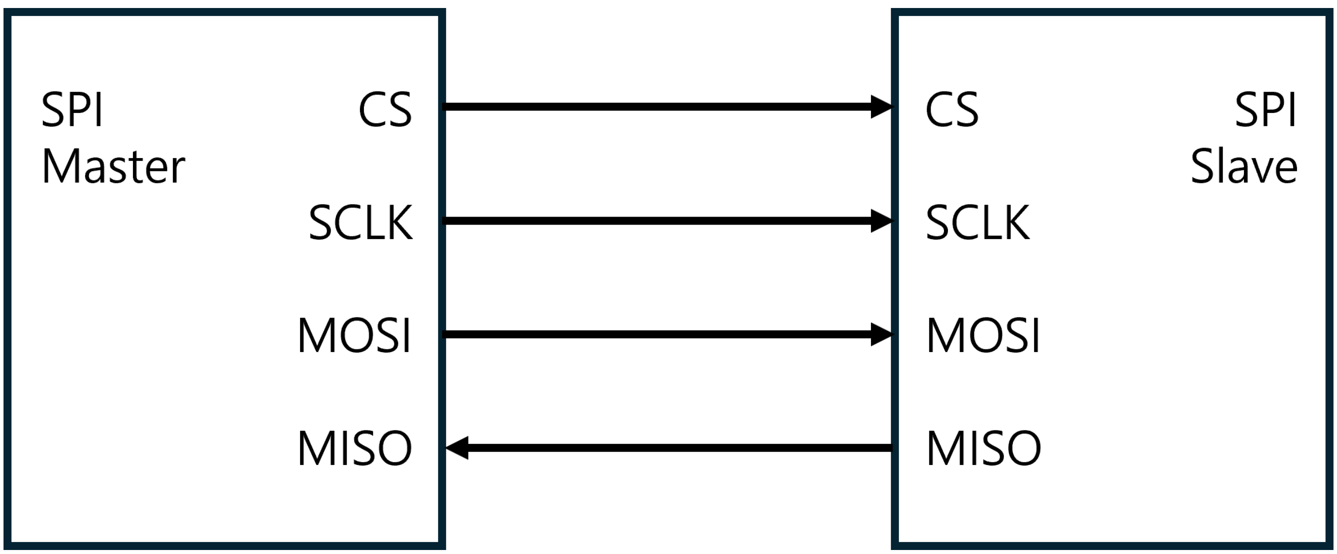

Figure 1-1. 4-Wire SPI Basic Schematic

2 SPI Communication Issues and Root Cause

Communication issues can occur for a variety of reasons. Noise from other circuits can be the cause, or other signals can couple to existing signals, causing malfunctions. This application note describes a case where a normally functioning AFE4xxx device malfunctions when the RF signal is turned on. Because EVBs are designed to eliminate interference and verify optimal device operation, it is difficult to identify issues that can arise in the complex system structure. Therefore, quickly and accurately identifying the cause and providing designs to customers when issues arise in the field is crucial.

Figure 2-1 shows normal SPI communication. Signals are exchanged periodically, indicating no issues on any pins. However, when AFE4xxx is in abnormal state, it shows behavior such as BG not functioning properly, inconsistent and no data is received.

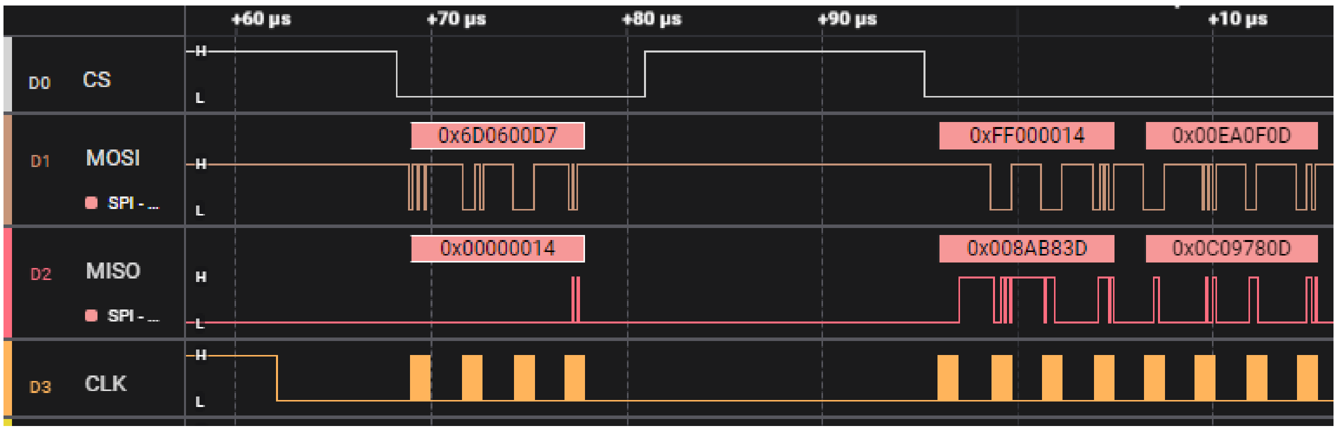

Figure 2-1. AFE4xxx Normal SPI Communication

Several tests confirmed that RF signals were affecting AFE4xxx SPI communication and attempted various designs to minimize redesigning effort and resolve the issue. External electromagnetic noise (EMI) tends to be more severe in high-frequency bands due to the antenna effect. Therefore, the user tried decreasing the SPI speed (frequency) compared to the previous setting, but the same issue occurred.

Therefore, when applying an RF signal directly to the SCLK line and verifying device operation, results were obtained similar to those observed in the field. This revealed that the RF signal coupled to the SCLK line affected the operating decisions. Figure 2-2 shows the test schematic for coupling noise effect of a RF signal applied to the SCLK line using a signal generator, and Figure 2-3 is a zoomed-in view of the rising edge. Due to glitches (noise) on the rising edge, the signal does not rise in a single low-to-high transition, but rather, after an additional cycle at the midpoint, rises. This noise introduced into the SCLK line caused the device to malfunction.

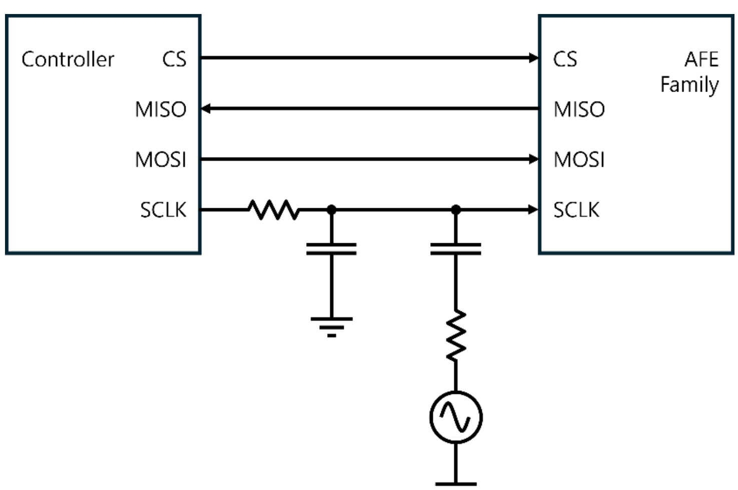

Figure 2-2. Test Schematic for Coupling Noise Effect

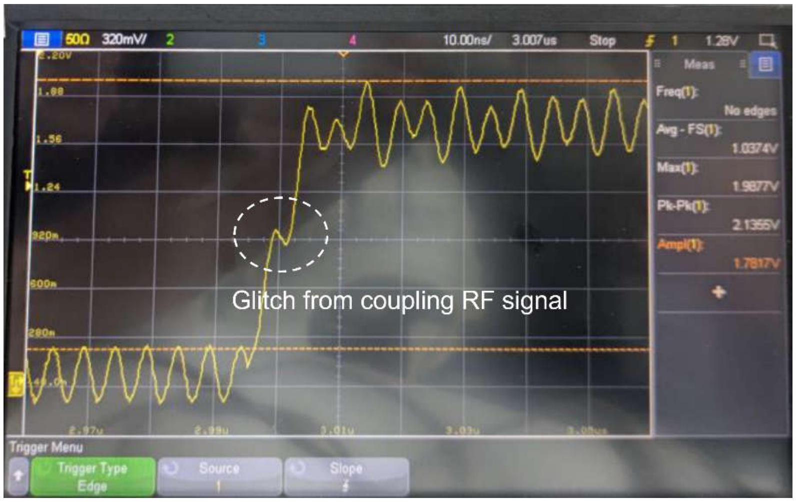

Figure 2-3. Measurement Result with External RF Coupling into SCLK Path

Figure 2-4 shows the impact of a glitch occurring on the rising edge. Glitches at the VIH and VIL levels cause malfunctions in the internal clock of the AFE. While a noise-free signal must rise evenly as the signal rises, the glitch causes a drop from high to low on the rising edge.

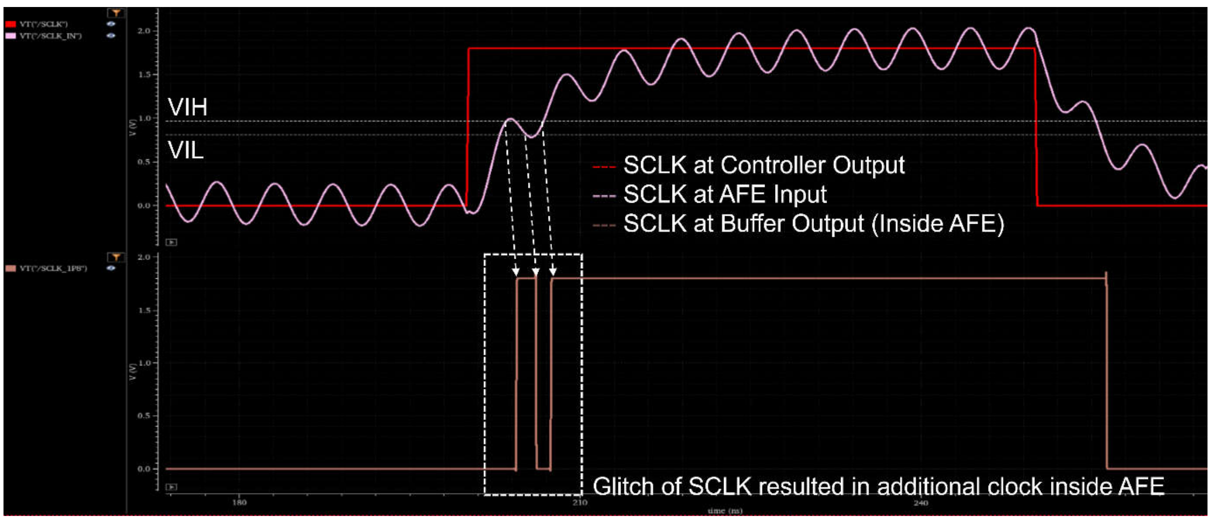

Figure 2-4. Measurement Result with Effect of Change in Hysteresis of Input Buffer

3 Design

A field-applicable design is to add a filter to the SCLK line to remove noise. Since SPI communication itself is not particularly fast, the possibility of additional filters affecting communication due to delays is very low. A low-pass filter is required to remove high frequencies. The cutoff frequency should be approximately three times the operating frequency and margin, taking into account the operating frequency. Figure 3-1 shows the LPF basic characteristic curve.

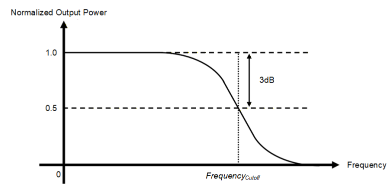

Figure 3-1. Low Pass Filter Characteristic Curve

Low pass filter (LPF) cutoff frequency is F_c. F_c expressed by the following equation:

$$F_c = \frac{1}{2\pi RC} \quad (1)$$

Furthermore, the filter must be placed as close to the slave, AFE4xxxx, and pin as possible to eliminate clock noise and maintain normal device operation. Placing the filter in the middle of the communication line or on the master side can result in noise re-introducing itself into the filtered signal. Figure 3-2 shows how to place the filter.

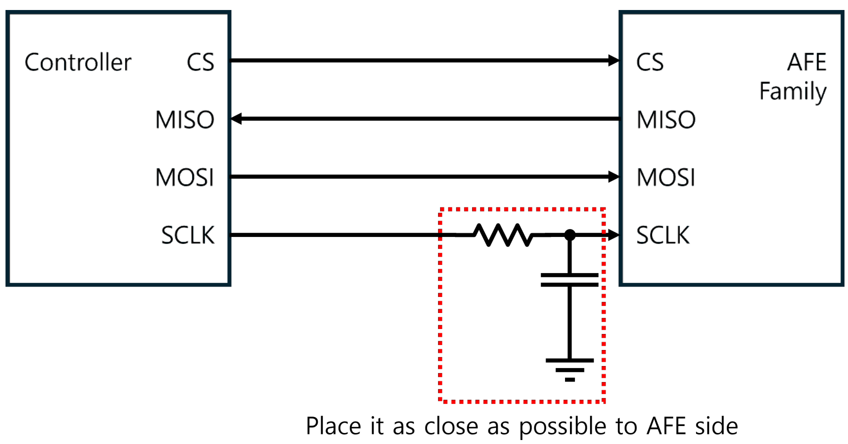

Figure 3-2. Proposed LPF Schematic into SCLK Path

Another approach is to increase the hysteresis margin of the SCLK buffer when designing the next version of the device. The trend in wearable devices is to minimize external noise to achieve power consumption, product size, and price competitiveness. Therefore, improving the hysteresis of buffers in developing next-generation products is something that must be considered not only for wearable devices but also for all devices targeting PE, and this performance increases the competitiveness of the product.

4 Summary

This application node proposes testing and designs for noise-induced SPI communication errors in smart devices. When SPI communication errors occur in applications with multiple communications, the first thing to check is whether the clock is properly input. Noise coupled to the clock signal can cause the AFE4xxx chip itself to malfunction. There are two ways to remove noise signals introduced into the clock: using a low-pass filter (LPF) to increase the buffer margin of the product hysteresis. However, when space and time constraints are limited, placing the LPF as close to the AFE4xxx (slave) as possible can resolve noise-induced issues.

5 References

1. Texas Instruments, *AFE4432 Ultra-Small, Integrated AFE for Optical Bio-Sensing*, datasheet.
2. Texas Instruments, *AFE4432 EVM User Guide*, user's guide.
3. Texas Instruments, *Single-Event Latch-up (SEL) Test Report for INA901-SP Current Sense Amplifier*, radiation report.
4. Texas Instruments, *Active Low-Pass Filter Design*, application report.