Technical Article

A Method for Isolated Voltage Sampling Using ADS7040 and General-Purpose Optocouplers

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This document was translated from a simplified Chinese source. (ZHCTA04)

In the motor drive sector, the MCU for motor control needs to receive signals to control the speed, direction, and other parameters of motors. For this reason, there is a demand for isolated voltage sampling. Isolated op amps and isolated ADCs are the most common methods for isolated voltage sampling, and here we show a scenario and specific implementation method for isolated voltage sampling using TI's low-cost, non-isolated ADC ADS7040 with general-purpose optocouplers.

In HVAC systems, thermostats provide a 0–10V voltage signal to DC fan coil units for speed regulation. Since there exists a ground potential difference between the thermostat circuit and the drive circuit of the DC fan coil unit, this 0-10V signal needs to be isolated. If the circuit is designed with the low-cost ADS7040 and general-purpose optocouplers, the circuit diagram is presented as follows:

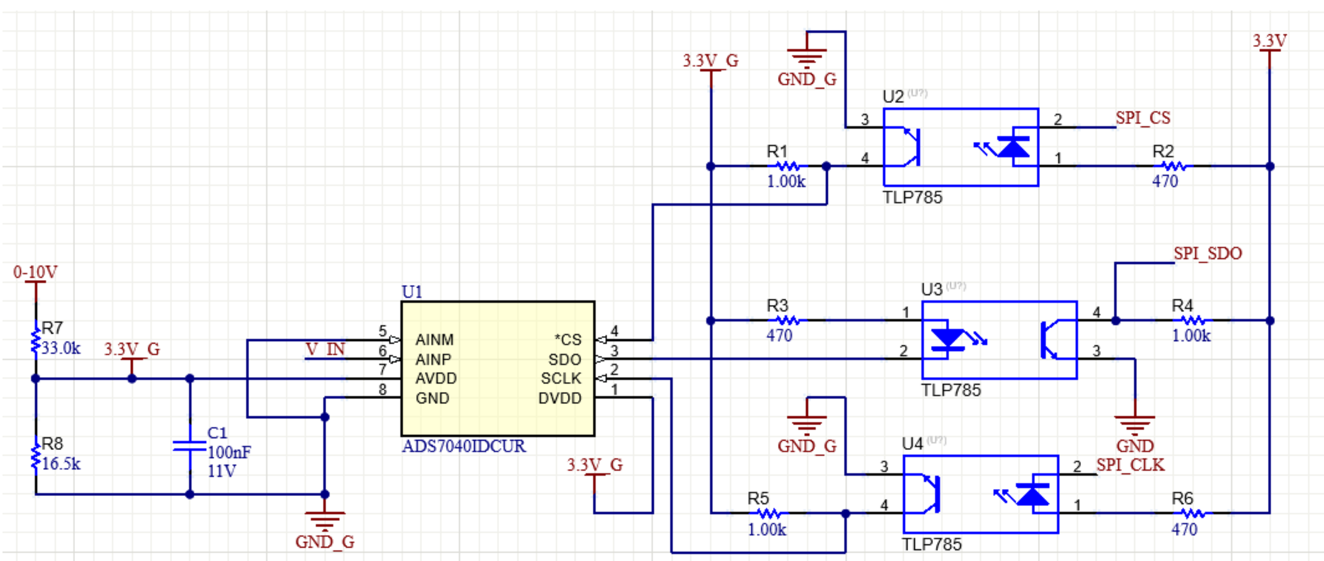

Figure 1. Circuit Diagram of ADS7040 with General-purpose Optocouplers

However, problems were observed in actual testing, as shown in the figure below: CLK was set to 16kHz, but it was seen that the CLK waveform was heavily distorted, not a rectangular wave; and the duty cycle was heavily narrowed, with SDO output errors.

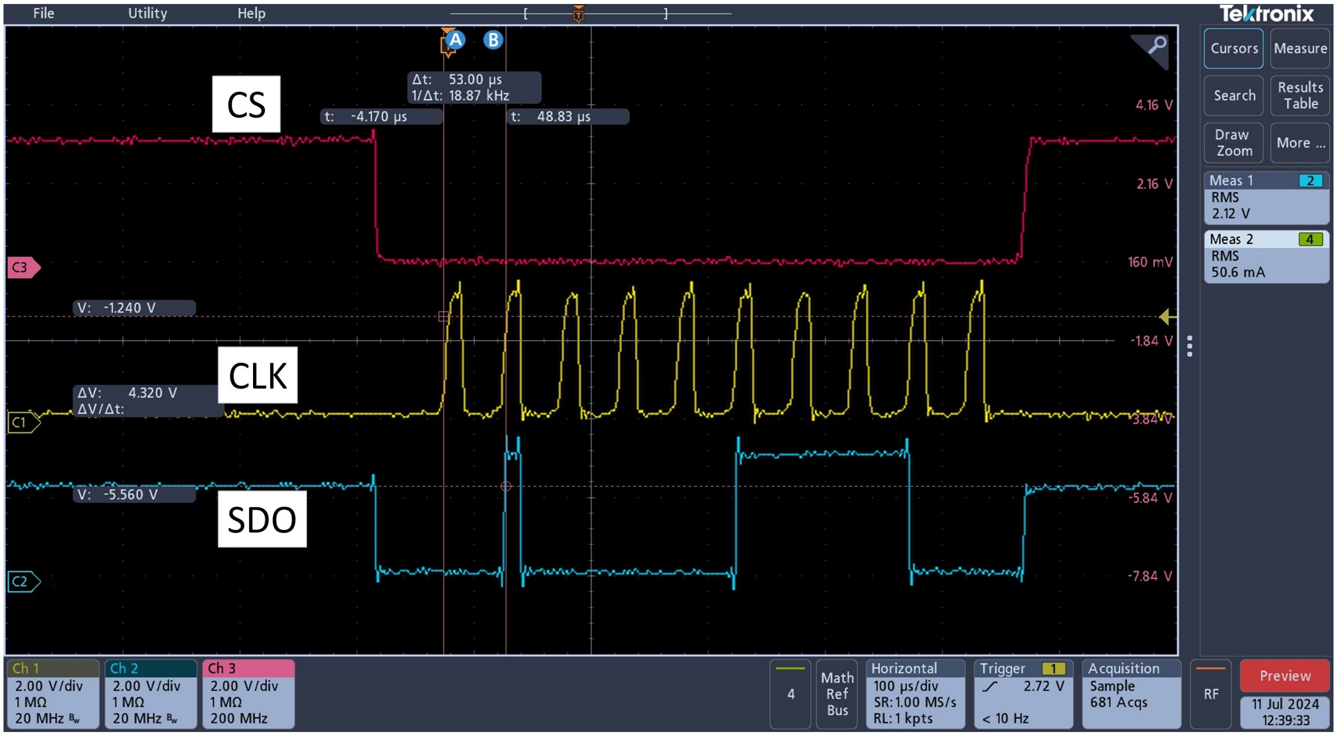

Figure 2. SPI Communication Waveform Diagram

The ADS7040 has a minimum SCLK frequency of 16kHz, indicating a period of 62.5us, and the duty cycle is 0.45-0.55, indicating that the delay of optocouplers cannot exceed 5% of 62.5us, that is, the rise and fall time of optocouplers cannot exceed 3us.

t_{ACQ}	Acquisition time	[illegible]		ns
f_{SCLK}	SCLK frequency	0.016	12	MHz
t_{SCLK}	SCLK period	83.33		ns
t_{PH_CK}	SCLK high time	0.45	0.55	t_{SCLK}
t_{PL_CK}	SCLK low time	0.45	0.55	t_{SCLK}

Table 1. ADS7040 Clock Frequencies

However, as indicated in the datasheet of a general-purpose optocoupler (see figure below), its typical rise and fall times are 4us and 3us respectively, while the maximum is 18us, indicating that general-purpose optocouplers cannot support SPI communication at 16kHz with a duty cycle of 0.45-0.55.

Rise time	t_r	-	4	18	µs	V_{CE} = 2V, I_C = 2mA, R_L = 100Ω
Fall time	t_f	-	3	18	µs	

Table 2. Rise and Fall Times of General-purpose Optocouplers

Therefore, improving the turn-on and turn-off speed of optocouplers is the key to solving the problem. Aside from the inherent physical limitations—such as the relatively slow response times of LEDs and phototransistors, which cannot be altered—the operation of optocouplers in the saturation region is a key factor for turn-off delays. When the light intensity received by the photosensitive triode is sufficiently high, its collector current (IC) causes the triode to enter the saturation region (VCE ≈ 0.2V). At this point, a large amount of charge is stored in the base region and the collector region. When the light signal disappears, the stored charge needs be discharged through the load resistor or external circuitry, resulting in a significantly extended turn-off delay (usually longer than the turn-on time). Since the turn-off delay of optocouplers is significantly extended in the saturation region, operation in the unsaturated region is a viable alternative. Yet, under unsaturated conditions, the optocoupler output transistor, though on, maintains a relatively high VCE that may range from several hundred millivolts to over 1V, which may exceed the MCU's maximum allowable low-level input voltage.

To address the issue where the VCE voltage remains excessively high at low input levels, consideration can be given to using the output of the general-purpose optocoupler to drive an external PNP transistor. This configuration allows the optocoupler operating in the unsaturated region to control the transistor operating in the saturated region, thereby achieving rapid switching performance. Since the optocoupler is required to operate in the linear amplification region while the PNP transistor is designed to operate in the saturation region, the selection of pull-up and pull-down resistors is of critical importance. The process is as follows:

1. Given that the source and sink current of the ADS7040 is 2mA, the forward current (If) is set to 2mA. Under this condition, the value of the pull-down resistor at the optocoupler input should be calculated as (3.3−0.7)/0.002 = 1.3kΩ.
2. Taking the TLP785 as an example, when VCE > 0.4V, the optocoupler operates in its amplification region, where the CTR remains stable between 100% and 150% (the CTR exhibits minimal variation with a stable IF and a temperature range of 10°C to 40°C), yielding a IC of approximately 2mA to 3mA.
3. To ensure that the optocoupler operates stably in the amplification region, a margin should be reserved, which requires the VB to be greater than 1V. Given $I_C = I_R + I_B$, if no transistor is incorporated, then Ib=0 and Ic=IR=3mA(max). When the pull-up resistor at the optocoupler output is set to 600Ω, the VB can be calculated as 3.3-0.003*600=1.5V. In this extreme case, the output voltage of the optocoupler reaches its minimum value, which is sufficient to ensure that the optocoupler operates stably in the amplification region.
4. When the transistor operates in the saturation region, the VEB is 0.9V maximum. Correspondingly, the VB can be calculated as 3.3-0.9=2.4V. Under this condition, the transistor can be turned on, while ensuring that the optocoupler operates in the saturation region.

Using the data signal output SDO as an example, the circuit is shown in the following figure.

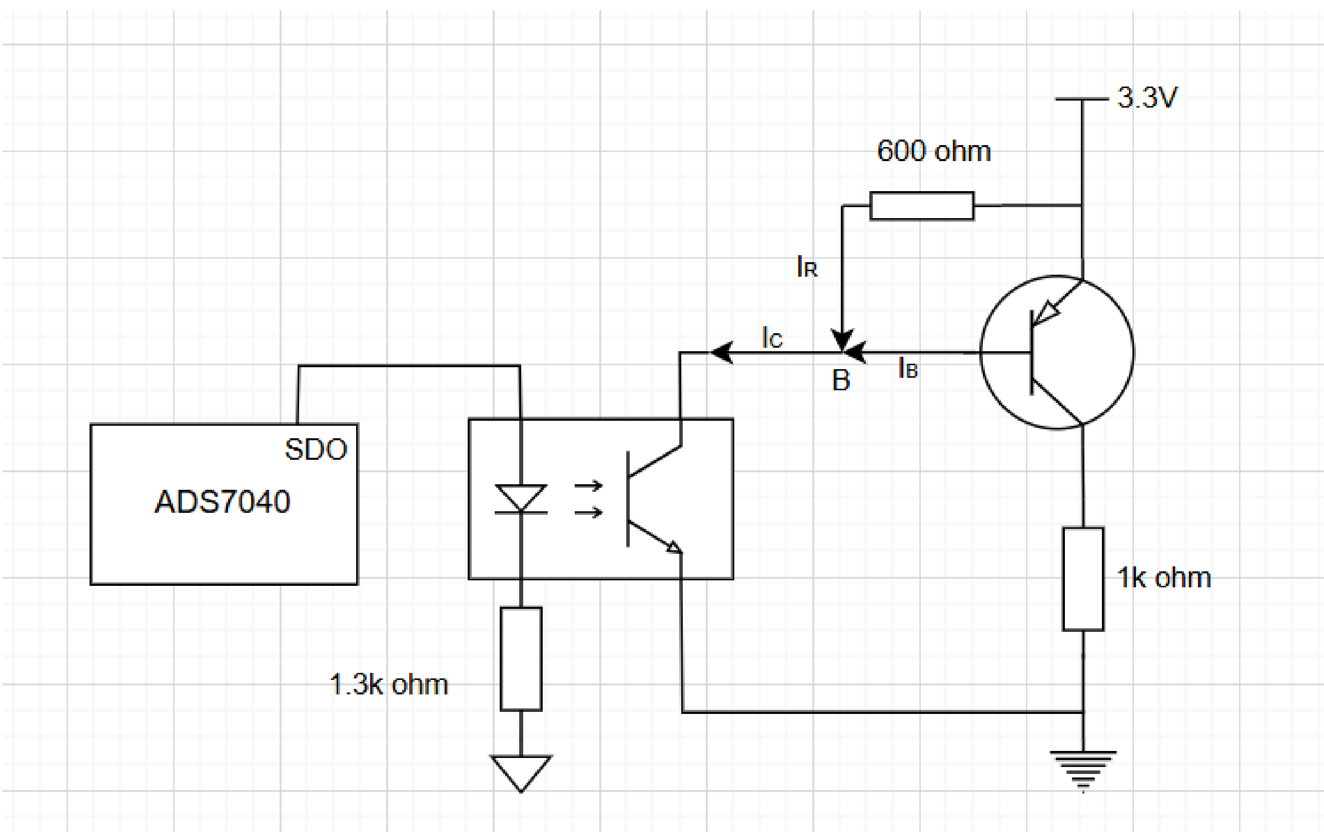

Figure 3. Data Signal Output SDO Circuit Diagram

Based on the above analysis, the circuit diagram for isolated 0–10V voltage sampling using the ADS7040 and general-purpose optocouplers is as follows:

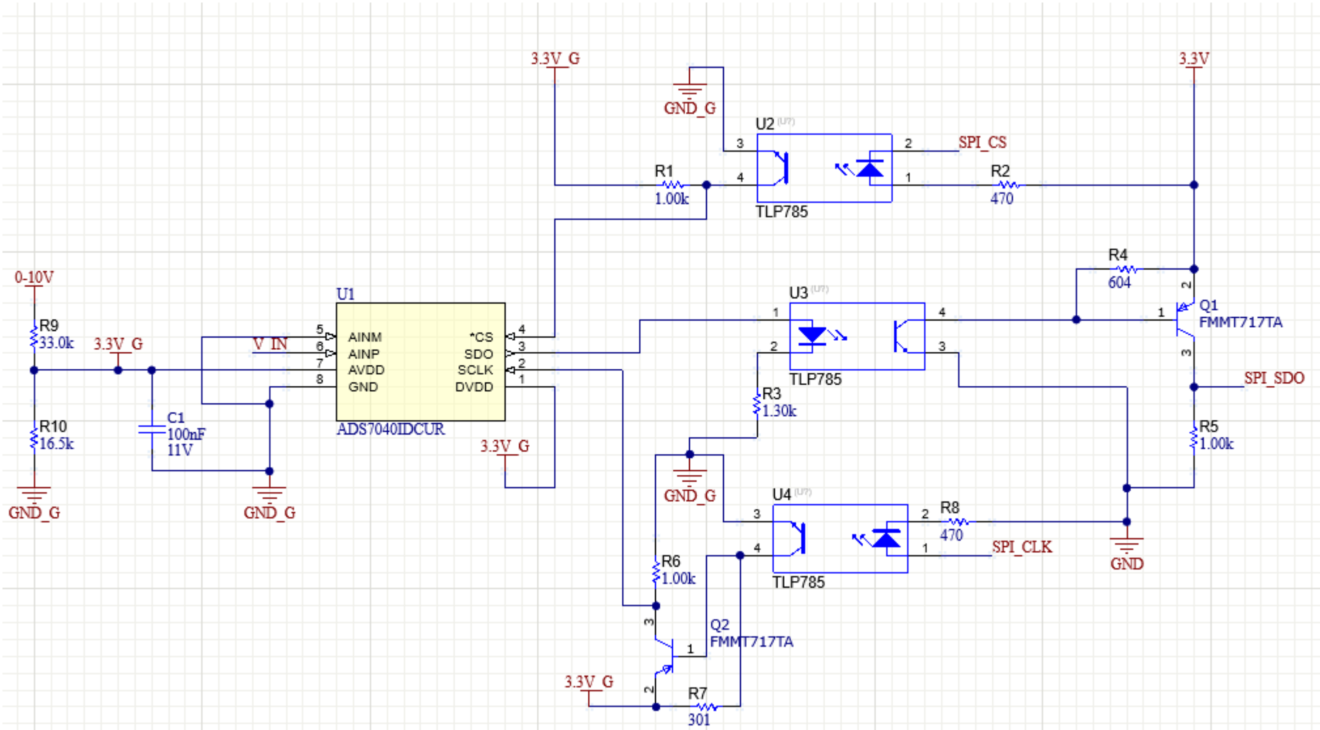

Figure 4. Circuit Diagram of ADS7040 with General-purpose Optocouplers and Transistors

As shown, PNP transistors are added at the SDO and CLK pins, whereas the CS pin—serving as a chip select signal with no chopping—does not need to add a transistor. When the optocoupler is on, its output is low and the base of the PNP transistor is pulled low, so the output of the PNP transistor is pulled high. When the optocoupler is off, its output is pulled high with a pullup resistor, and the voltage difference between the emitter and base of the PNP transistor, VEB, is <0.7V, so the PNP transistor is turned off and the output is pulled low with a pull-down resistor.

To verify the reliability of this circuit, SPI communication was established between the ADS7040 and TI's MSPM0G1506 MCU. The analog signals (0V, 4V, 6V and 10V) are applied to test the CS, CLK, and SDO waveforms on the MCU side, as shown below, with the blue signal being CLK, the green signal being CS and the red signal being SDO.

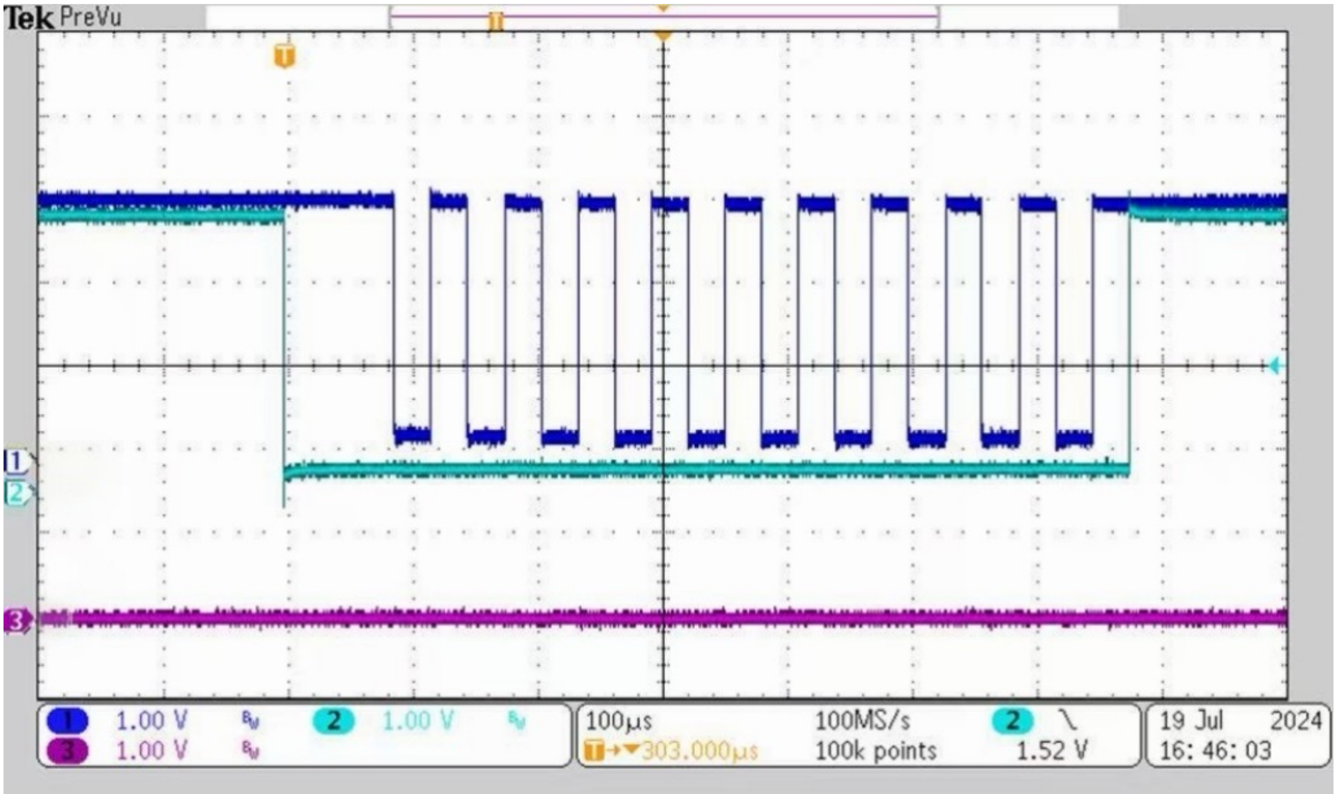

Figure 5. CS, CLK and SDO waveforms on the MCU side with 0V signal input

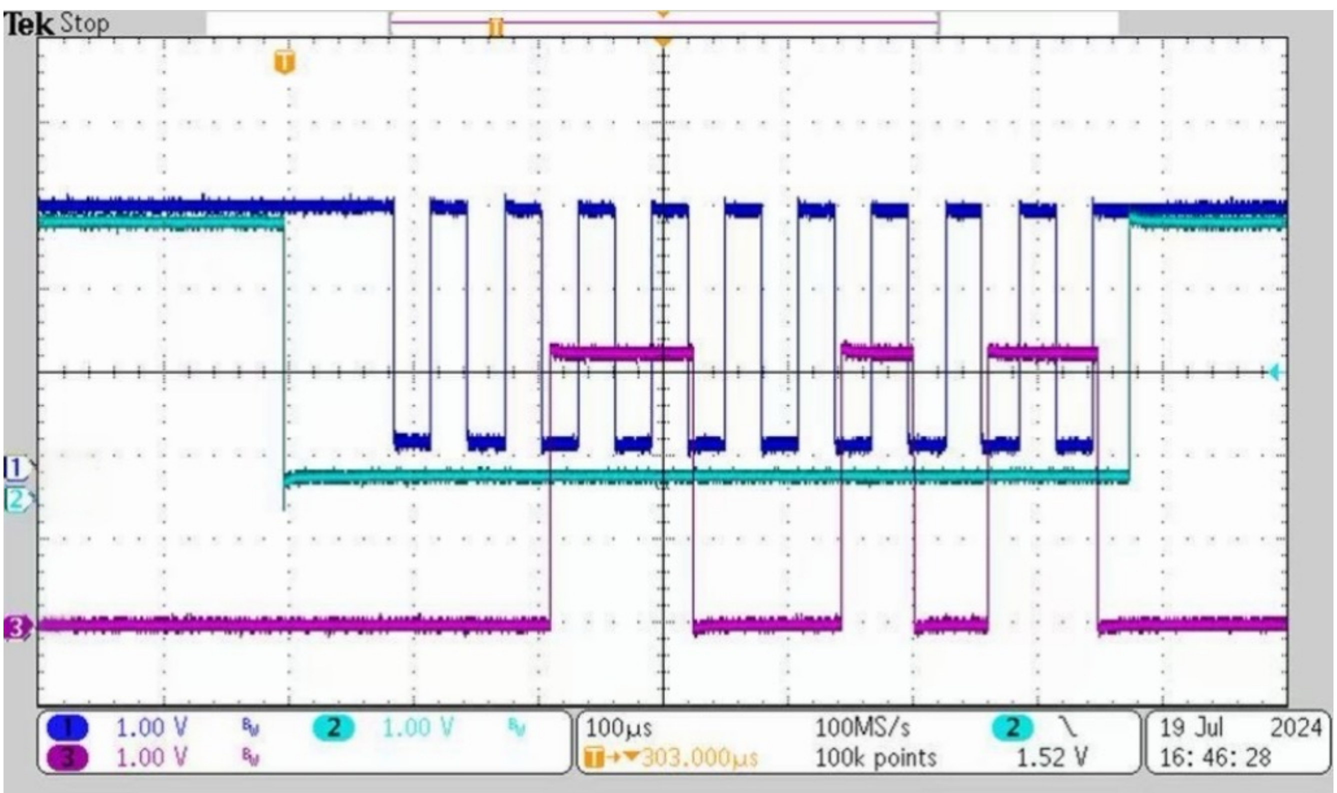

Figure 6. CS, CLK and SDO waveforms on the MCU side with 4V signal input

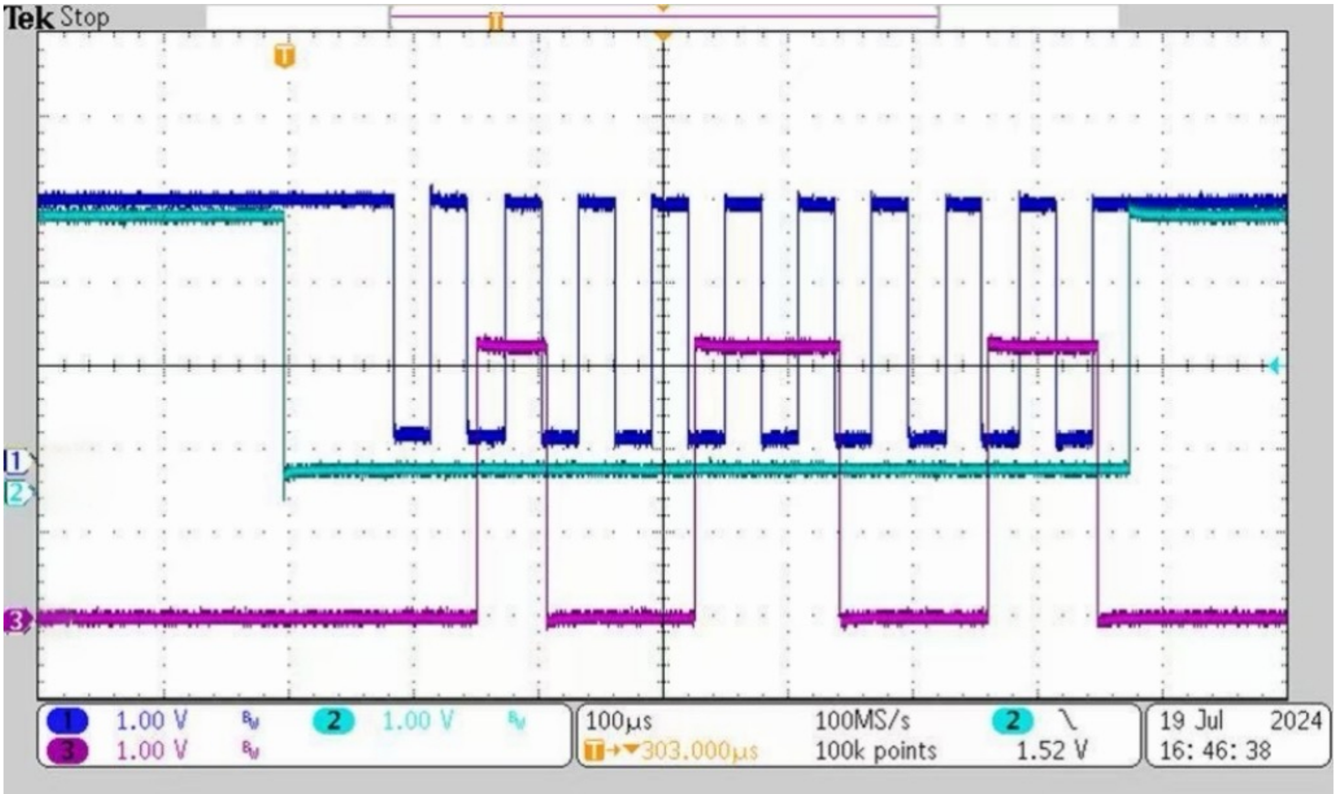

Figure 7. CS, CLK and SDO waveforms on the MCU side with 6V signal input

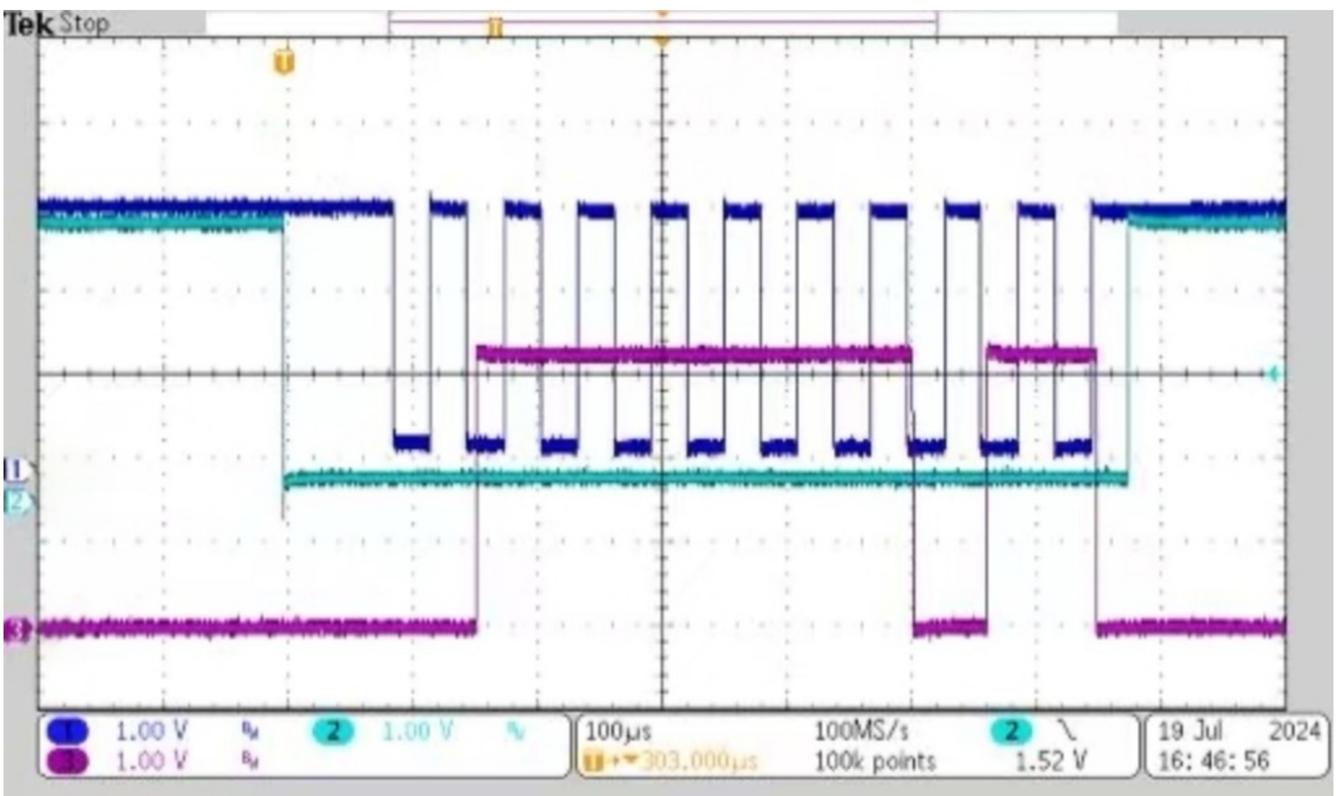

Figure 8. CS, CLK and SDO waveforms on the MCU side with 10V signal input

As you can see from the diagram, the waveforms of CLK, SDO and CS are all normal, enabling the correct transmission of SPI signals to the MCU.

Meanwhile, for general-purpose optocouplers, TI offers the ISOM8110 opto-emulator, which is pin-to-pin compatible with the industry-standard optocouplers, delivering significant reliability and performance advantages. Its internal transmission medium is SiO_2 instead of light, so there is no optical degradation. It also features a wider operating temperature range, a current transfer ratio (CTR) that remains stable over the entire operating temperature span, as well as high bandwidth and low power consumption. This is why the same accurate SPI waveform can be obtained by replacing the general-purpose optocoupler above with a pin to pin one.

In summary, using the ADS7040 and ISOM8110 (or a general-purpose optocoupler) to transmit 0-10V analog signals enables truly isolated, low-cost and reliable SPI communication.