AS65xx Laser Range Finder

Improving Precision using TDCs

AS65xx application note

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Content Guide

1 Introduction

There are several different approaches to build a laser rangefinder. They are similar in that they all use some form of light pulse that is sent out and then somehow received. Once the return pulse has been received, some simple mathematical or geometric formulas are used to calculate the distance traveled. It's the method of receiving and the fundamentals associated with calculating the distance where these different methods differ.

Some of these methods are for example:

- Triangulation
- Modulated Continuous Wave
- Time-of-Flight
- …

Each of these different methods has their own set of advantages and disadvantages.

Table 1: Overview of different methods

Method	Measuring Range	Accuracy	Comment
Triangulation	< 10 m	several µm	depends on the surface, inexpensive, robust
Modulated Continuous Wave	< 200 m	approx. 10 cm	low production costs, slow measurement
Time-of-Flight	several km	several mm	short reaction time, expensive, no aperture

Note for eye-safety

The longer the distance the weaker the reflected signal. Laser power must be increased to compensate for the weaker return signal. But due to eye safety regulations the total laser power is limited. Therefore, it is mandatory to use pulsed lasers for long distance applications. The shorter the laser pulse width the higher the peak amplitude can be.

This application note describes the implementation of a TDC in a TOF laser rangefinder that is based on ScioSense TDC-AS65xx Time-to-Digital Converter. It describes only the use of the TDC, not the optical part and analog electronics.

1.1 Time-of-Flight

Time-of-Flight – this is the time taken for a light pulse to travel to the target and back. With the speed of light known, and an accurate measurement of the time taken, the distance can be calculated. Many pulses are fired sequentially, and the average response time is used to further improve accuracy. This technique requires very accurate sub-nanosecond timing circuitry.

Measuring distances with lasers or laser scanners is well established – you will find this technique in geodesic systems, security systems, production control systems and even with golf range finders. Different methods are available based in the distance to be measured. Small distances are measured by triangulation. Using this method, the achieved resolution will be in the range of micrometers, but the maximum range is limited to only a few meters. Up to distances of 100 m people often use the phase shift measurement technique. The laser light is modulated and the phase shift between outgoing and incoming light gives the distance. To reach a resolution in the millimeter range very high sampling rates are necessary. Only low measurement rates with high current consumption are possible.

With Time-to-Digital-Converters (TDC's) you choose a direct way to digitize the Time-of-Flight. It is possible to measure the time-of-flight of light directly. The principle is easy - the details are tricky. It is well known that the velocity of light is very high.

$$c = 299{,}792{,}458\, {}^{m}/_{s}$$

$$c = velocity\ of\ light$$

Because of this, one must deal with very short times. In only one microsecond the light passes 300 meters! High resolution therefore requires the highest precision in time measurement. Usually, the ray of light will be reflected off an object or mirror. Therefore, the light passes the distance twice. So, we will have:

$$distance = c * \frac{time\ of\ flight}{2}$$

Table 2: Typical Time of Flight conversion in Distance

Time of Flight	Distance
66.67 µs	10 km
2.4 µs	360 m
6.6 ns	1 m
66 ps	10 mm
10 ps	1.5 mm
6.6 ps	1 mm

This is the range well suited for use of the TDC AS65xx. This single-chip TDC has a single-shot resolution 10 ps which is equivalent to 1.5 mm distance. The challenge here is noise-free transmission and reception optics. Ultimately, this limits the resolution of corresponding distance.

The AS65xx is a high-performance time-to-digital converter (TDC) frontend device. It is a derivative of TDC-GPX2.

AS65xx achieves high measurement performance and high data throughput. Configuration flexibility and unlimited measurement range cover many applications, ranging from portable handheld laser range equipment to ambitious high performance time-of-flight measurements.

In the following we look at the LIDAR (**Li**ght **d**etection **a**nd **r**anging / **Li**ght **i**maging, **d**etection **a**nd **r**anging) application in detail:

2 LIDAR Application

General Description

The table below shows a summary of the main differences between the high-performance TDCs recommended for LIDAR applications.

Table 3: Summary of different current high-end TDCs

	TDC-GPX2	**AS6500**	**AS6501**
Input Channel(s)	4x (LVDS / CMOS)	4x (CMOS)	2x (LVDS / CMOS)
Resolution [ps] / High Resolution [ns]	20 / 10	20 / 10	20 / 10
Pulse-Pair Resolution [ns] / Combined Channels [ns]	20 / 5	20 /20	20 / 5
Interface	LVDS / SPI	SPI	LVDS / SPI
Measurement Rate [MSPS]	<70 (peak)	<2	<70
Operating Supply Voltage [V]	2.4 to 3.6	2.4 to 3.6	2.4 to 3.6
Package	QFN64	QFN40	QFP48

Block Diagram

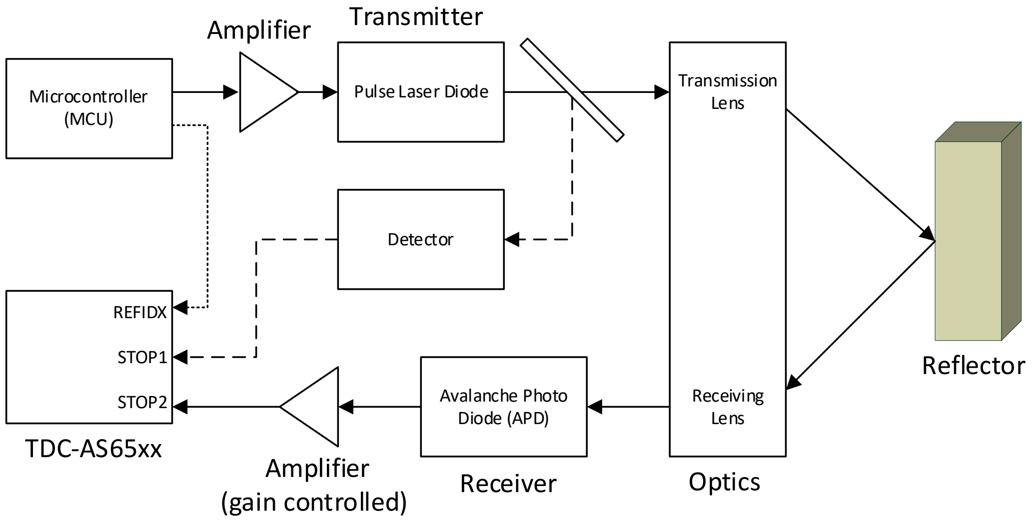


Figure 1: Block Diagram - LIDAR

Temperature effects on the transmitting and receiving paths are eliminated by measuring the time interval between a reference beam and the reflected beam. Using pin RSTIDX the internal counter for the reference index is set back to zero by the microcontroller. This option may simplify the overview on the reference index in the output data stream. The optical reference is given to STOP1, the reflected beam to STOP2. The difference STOP2 minus STOP1 corresponds to the distance to the reflector and back.

Advantages

- Measurement down to zero ps
- Averaging gives real improvement

Calculation of Time Differences

The results of the AS65xx are the time intervals from stop event pulses to the preceding reference clock pulses. In many applications, the time difference between stop event pulses is desired. This happens in the case of a quartz as a reference clock. Depending on the application and the measurement setup, several approaches are possible to calculate the time between two stops in the connected microprocessor or FPGA.

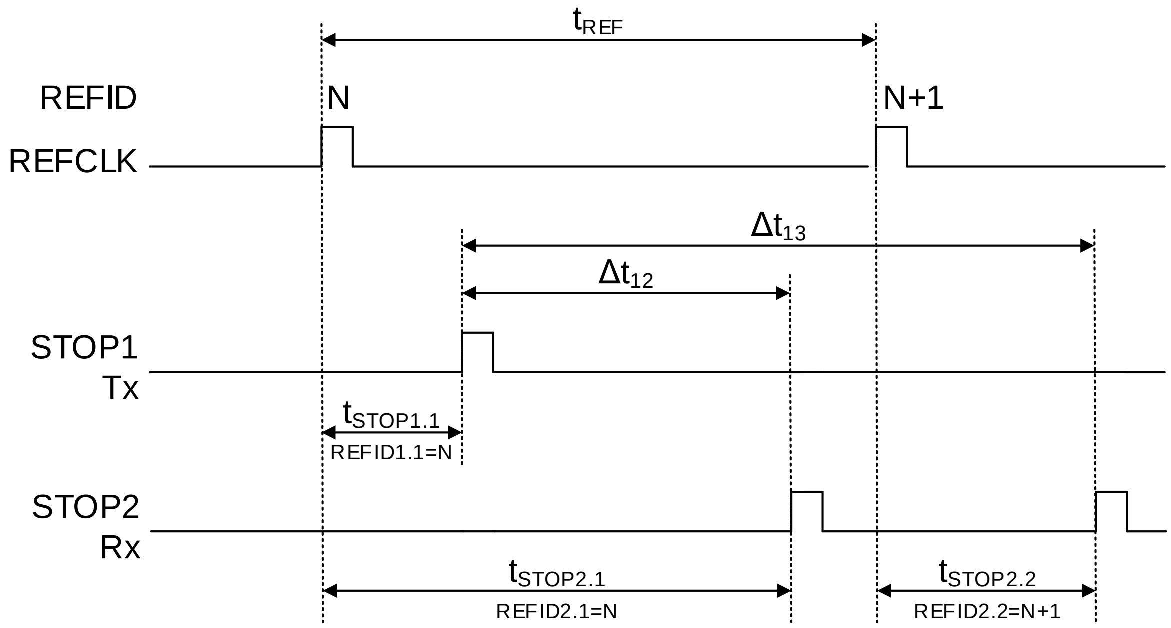


Figure 2: Calculating Time Differences

General Approach

On the output interface, either SPI or LVDS, both data REFID and TSTOP are available. With this data, it is possible to calculate time differences between stops.

In the special case where the reference index of Tx (REFID1.1) = reference index of Rx (REFID2.1), it is not necessary to readout the REFID:

- Stops occur in the same reference clock period

In applications where stops always occur in the same reference period, it is not necessary to read out the reference index. It is sufficient to read out just the stop results and to calculate the difference:

$$\Delta t_{12} = (t_{STOP2.1} - t_{STOP1.1})$$

The maximum time difference depends on the bit width of the reference index (see the data sheet for the AS65xx).

$$\Delta t_{13} = (t_{STOP2.2} - t_{STOP1.1}) + (REFID2.2 - REFID1.1) * REFCLK\_DIVISIONS$$

3 Example

This is a generic code example for a complete laser rangefinder measurement cycle, written for a STM32 microprocessor.

Preparation procedure:

- Reset the chip to power on state by opcode spiopc_power
- Write configuration registers by opcode spiopc_write_config
- Optional, verify configuration by opcode spiopc_read_config
- Initialize and restart measurements by opcode spiopc_init

Before triggering Laser, the FIFOs of STOPx are read as a long and should be 0xFFFFFF to be sure that all FIFOs are empty.

After triggering the Laser and detecting the falling edge of interrupt, do a byte-wise readout of the results (including REFID) from the read registers by opcode spiopc_read_results. A continuous readout is assumed as long as the interrupt is on LOW level. The interrupt goes back to HIGH when all FIFOs are empty.

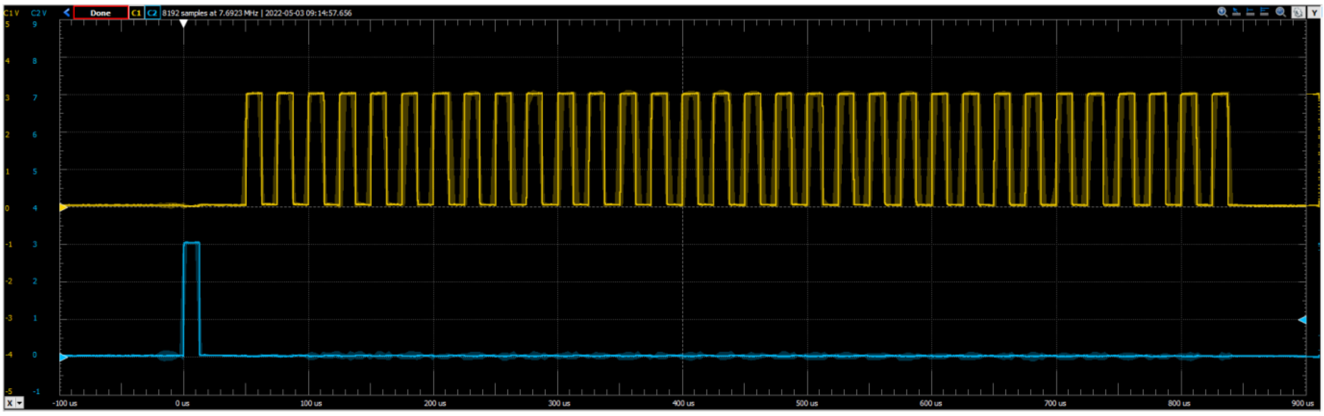
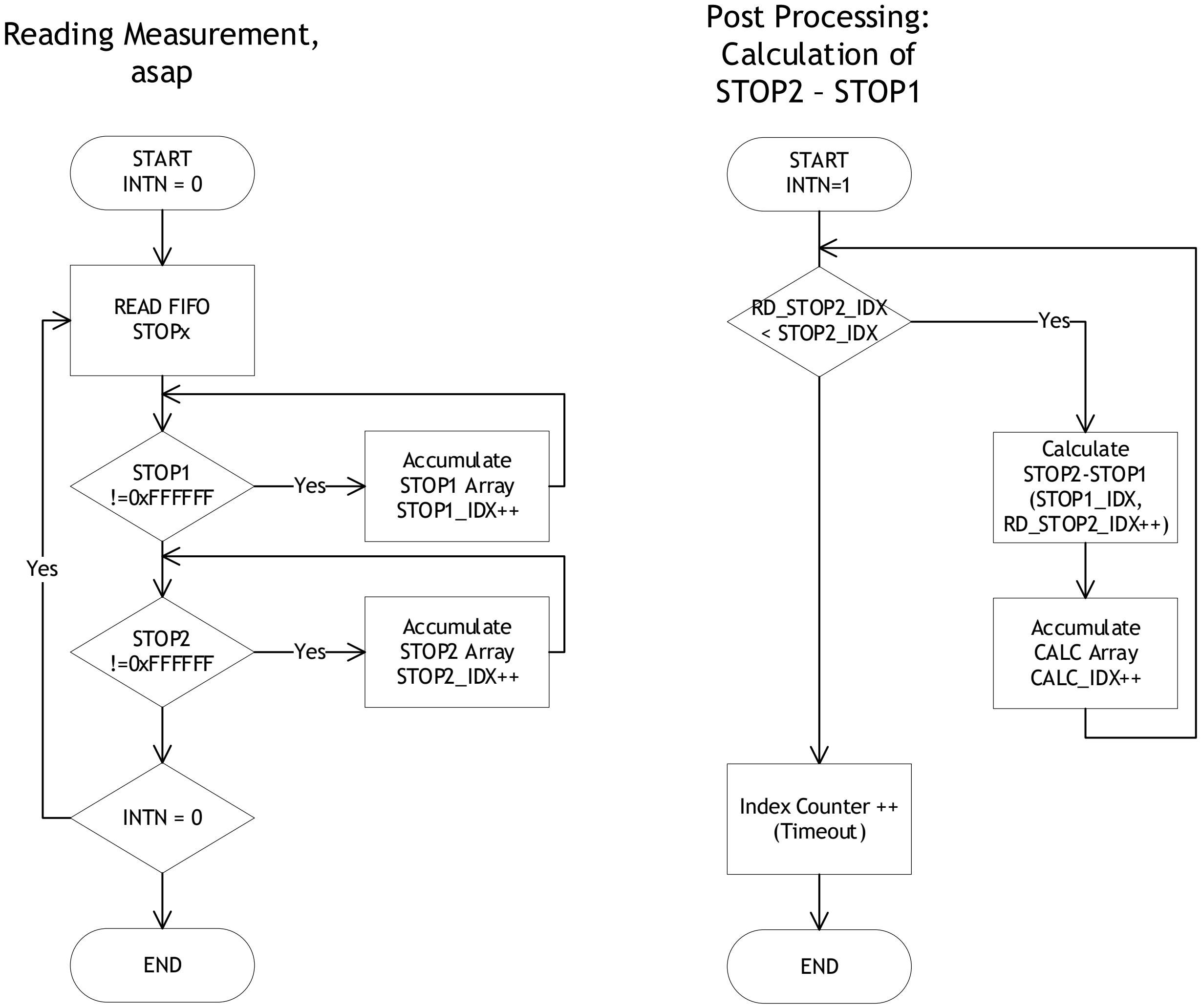


Figure 3: Triggering Laser (Tx in blue), Received Pulses (Rx in yellow)

The post processing, calculation of STOP2 minus STOP1 is shown in next section.

3.1 Detailed Flow Chart



3.2 Example Code

The whole source code can be downloaded from our download center.

Link: < https://downloads.sciosense.com/as6500/ >

The SPI interface is configured to 20 MHz.

A waveform generator is used to generate 32 reflected pulses (Rx) and is triggered by STM32 (Tx). The STM32 controller also resets the reference index of AS65xx.

After all results have been read and INTN is HIGH again, post-processing is performed. This happens 10 ms later in order not to load the maximum processor line for the previous reading of the measured value.

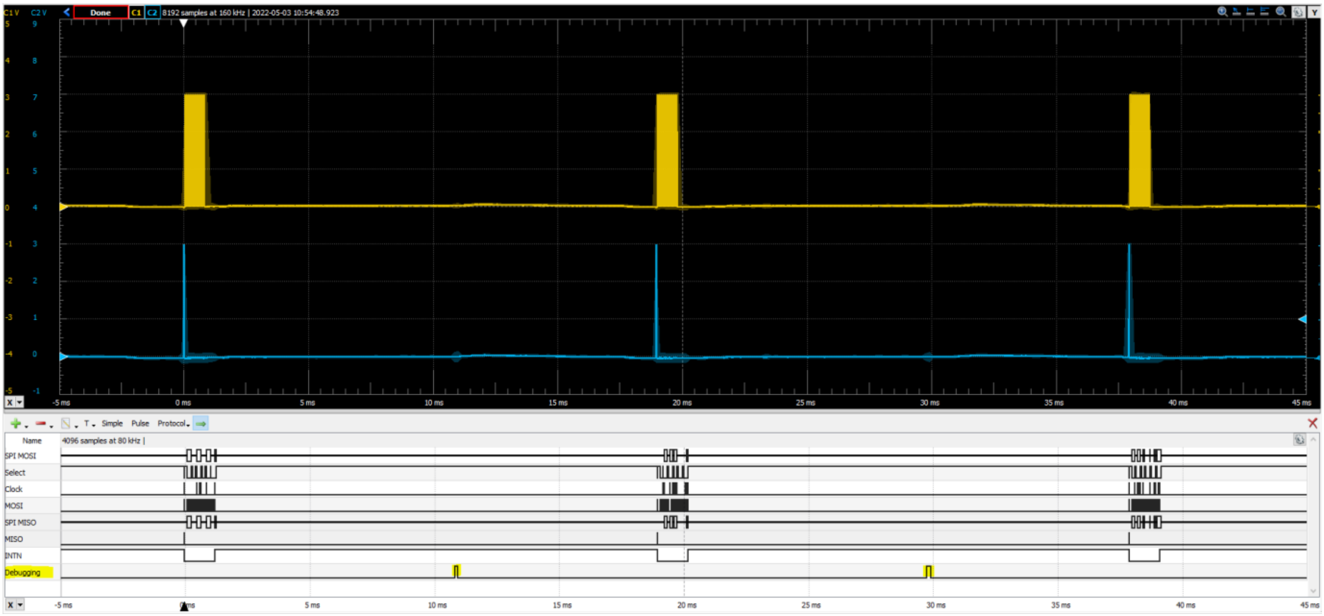


Figure 4: Complete Measurement Sequence, including Post Processing (Debugging Line)

In case of using HAL SPI functions, a maximum received pulse to pulse spacing of about 21 µs is required to get all 32 results.

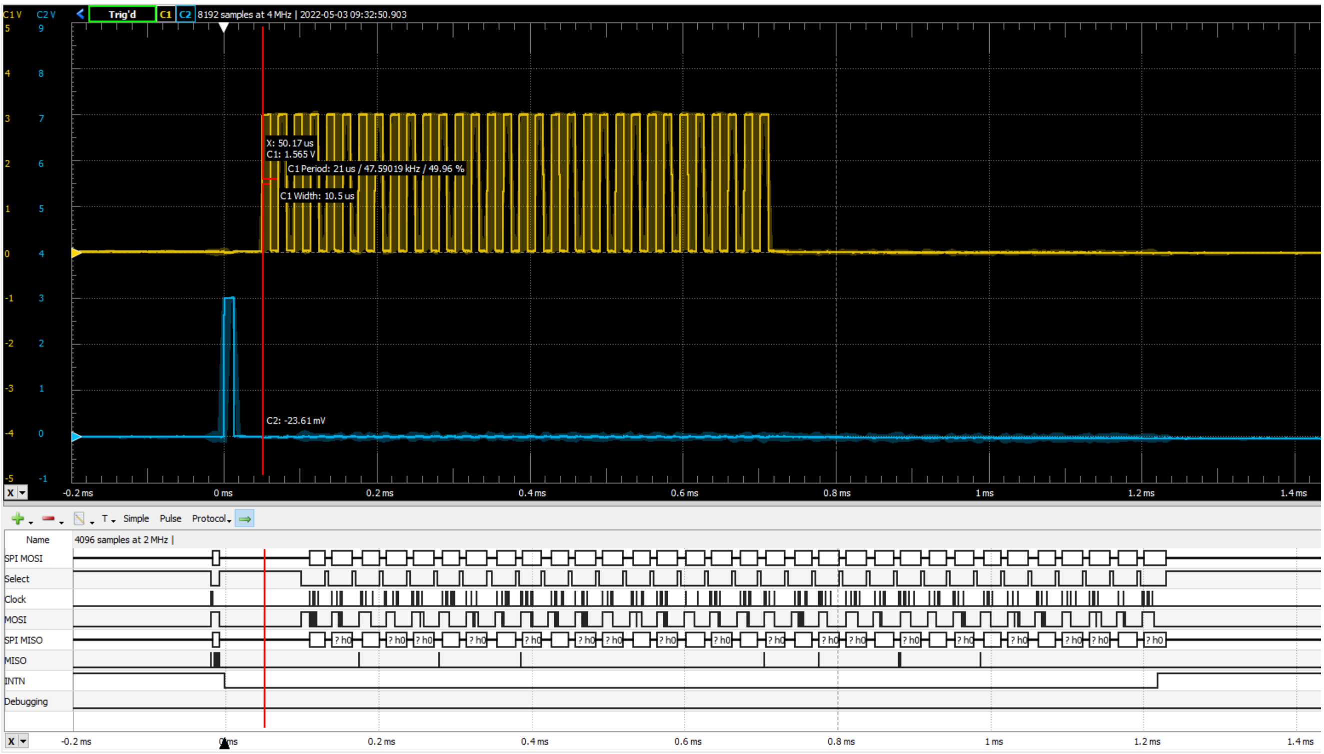


Figure 5: Readout, using HAL SPI Function

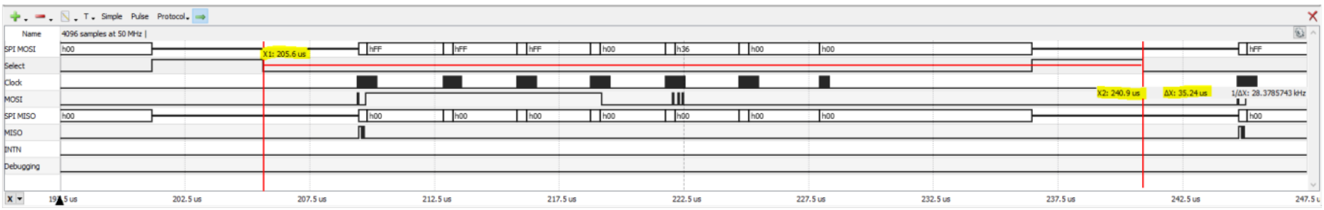


Figure 6: One Readout in 36 µs, using HAL SPI Function

To improve the read to maximum and to get rid of interbyte gaps, DMA controller should be used. MY DMA function improves the received pulse to pulse spacing down to about 8 µs to get all 32 results.

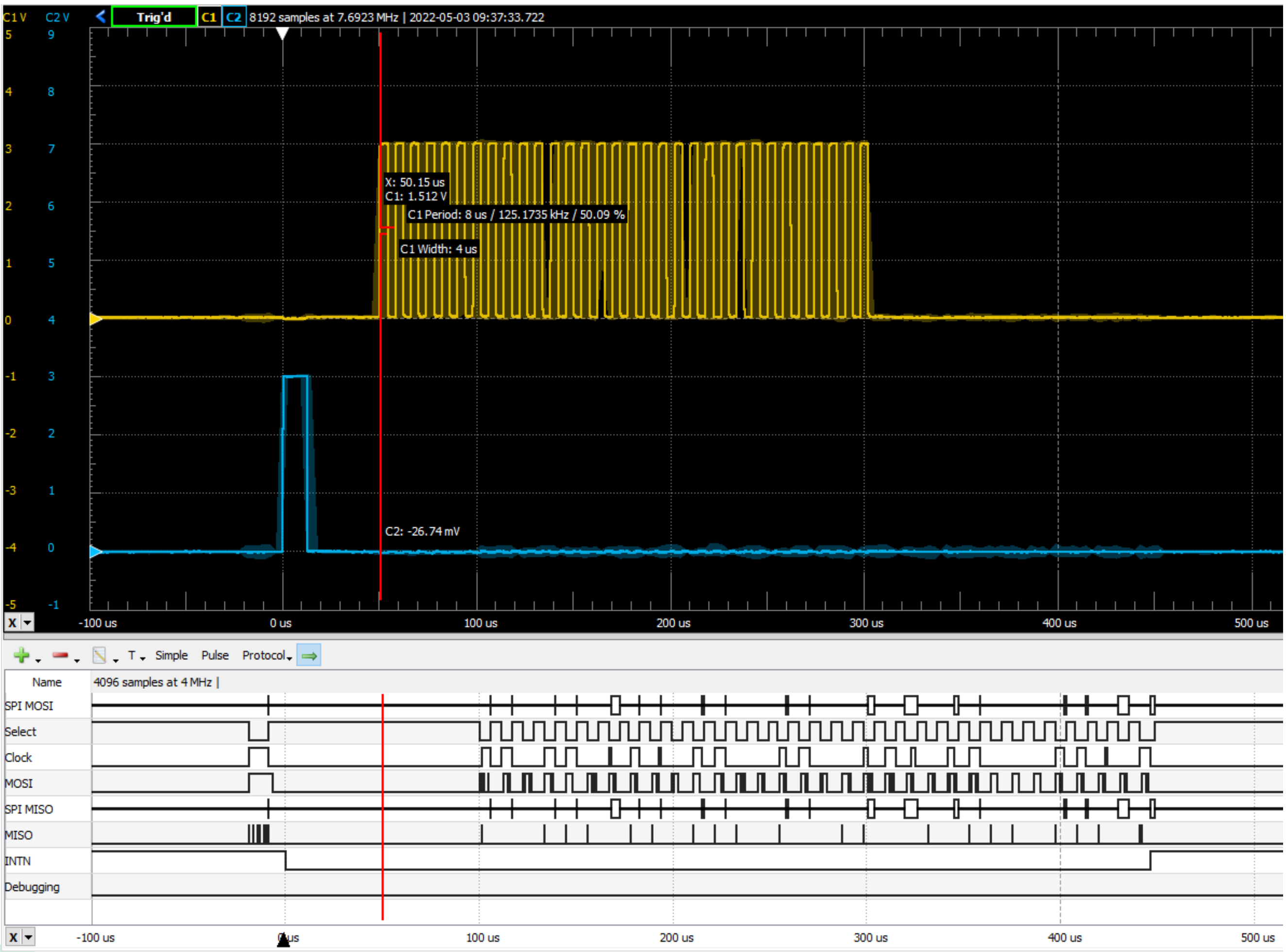


Figure 7: Readout, using MY DMA Function

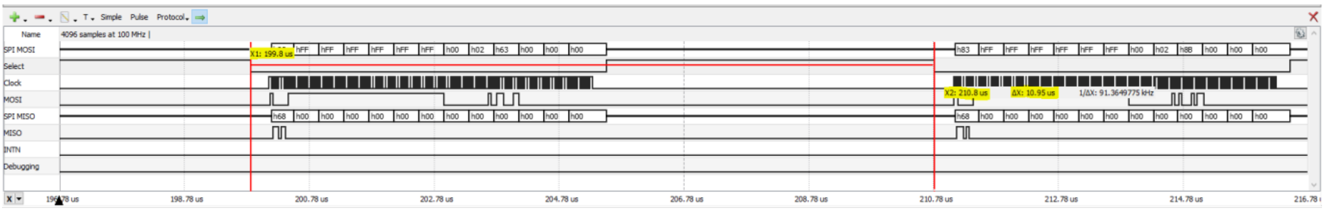


Figure 8: One Readout in 11 µs, using MY DMA Function

3.3 Example Code 2

A typical User case is using STOP1 as ‘Start’ to trigger the laser and measure several pulses on STOP2 as ‘Stop’ during ‘Signal Valid’ phase.

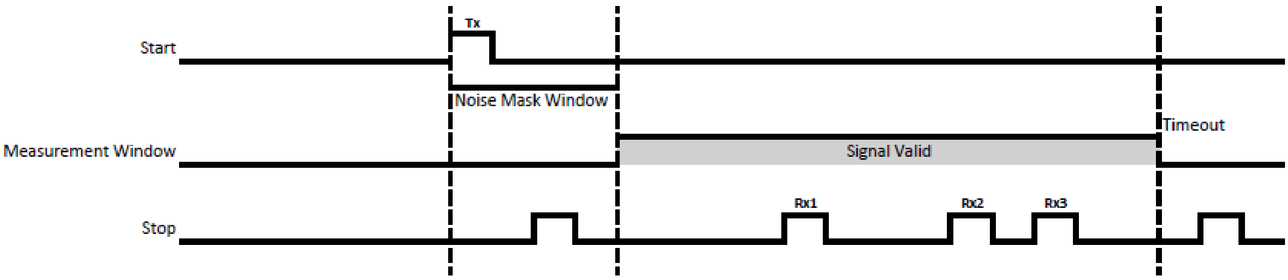


Figure 9: Typical User case, including ‘Noise Mask Window’, ‘Signal Valid’ and ‘Timeout’

All measured values are only stored in the RAW value array if the pulses are measured in ‘Signal Valid’ phase. Here are 32 pulses used. During the detected pulse sequence, the AS65xx must measure the values to keep the FIFOs empty, means to clear the INTN.

After the pulses sequence or after ‘Timeout’, the post processing routine can be used to calculate the time of flight (e.g. difference of rising edge of ‘Stop’ minus rising edge of ‘Start’), the pulse width (as long as the configuration CHANNEL_COMBINE = ‘PULSE_WIDTH’ (2) is used to get rising and falling edge of Rx).

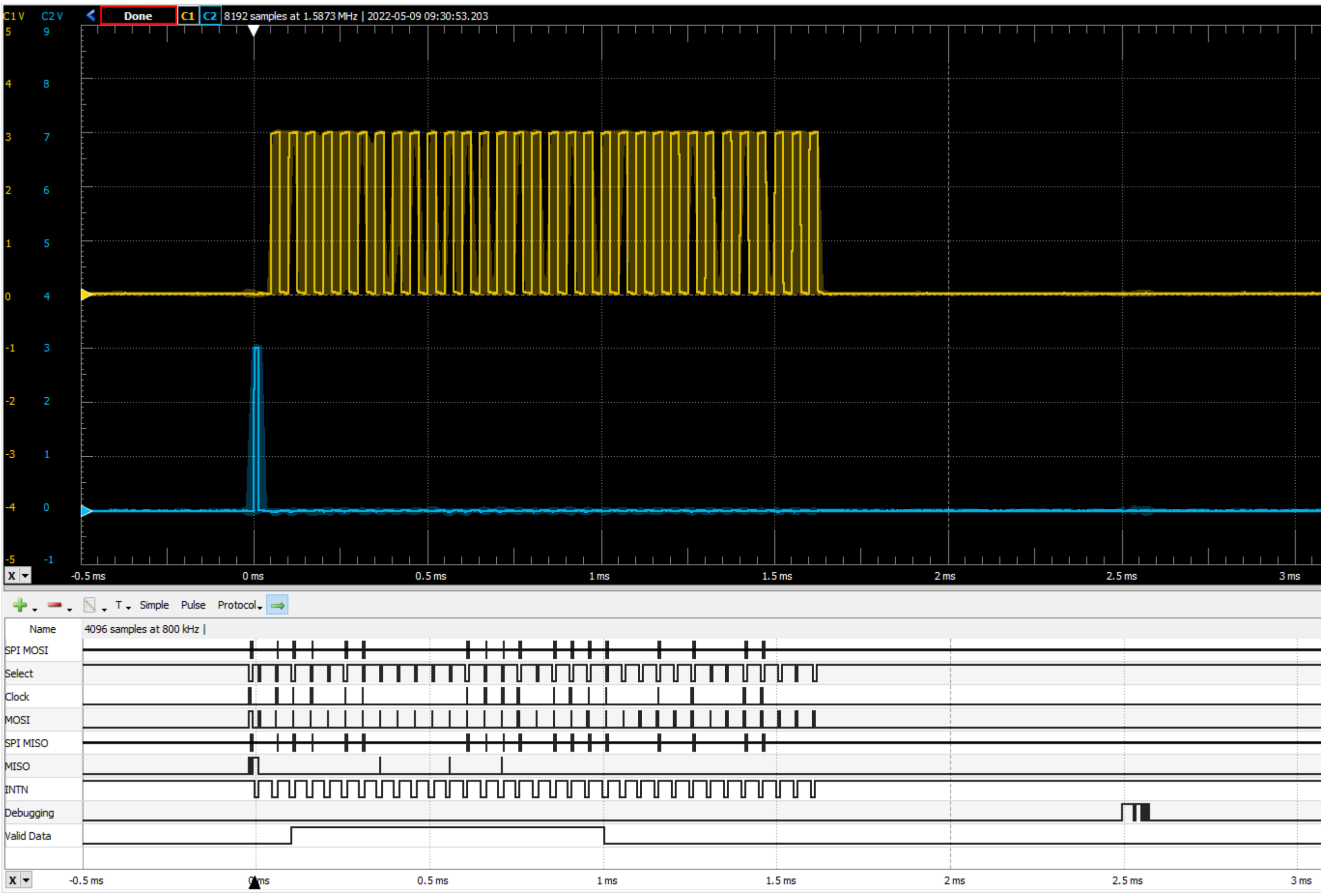


Figure 10: Complete Measurement Sequence, including Valid Data (between 100 ns and 1 ms) and Post Processing (at 2.5 ms)

3.4 Advantage/Disadvantage of used SPI Function

SPI Main Features

- With normal use of the SPI Interface (HAL SPI Function), the interbyte gap is disadvantageous when reading out asap.
- Chip Select (SSN) pin management of microcontroller can be used by hardware or software. Due to long byte sequences, controlling of SSN by software is preferred.
- Only when using '1-byte' transmission and reception, DMA can be used with controlled hardware chip select pin. Due to longer byte sequences, because of insufficient usage of SSN, HAL DMA function has to be modified and that's why MY DMA function is used in our example.

Short Description of MY DMA Function

- MY DMA only uses the required register accesses of the microcontroller and controls the SSN via GPIO.

4 Copyrights & Disclaimer

5 Revision information

Table 4: Revision history

Revision	Date	Comment	Page
1	24.05.2022	First edition	All

Note(s) and/or Footnote(s):

1. Page and figure numbers for the previous version may differ from page and figure numbers in the current revision.
2. Correction of typographical errors is not explicitly mentioned.

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