Application Report
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Short Time Measurement Using TDC7201

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ABSTRACT

Time-to-digital converters are used in measuring time-of-flight in multiple end applications such as drones, range finders, machine vision, robots, etc. These end applications can either use light waves, ultrasonic waves or other technologies such as RADAR. However, in each of these cases, time-of-flight between the transmitted wave and the reflected wave provides us with the distance traveled. Speed of light in air is multitudes of orders higher than the speed of sound waves in air and hence the total distance traveled by light waves is much higher during the time frame. For very short distance measurements (less than 2 meters), time-of-flight (TOF) is in the range of 0ns to 12ns and a centimeter accuracy corresponds to 67ps. The objective of this application note is to describe a method for measuring time periods down to 0.25ns using the TDC7201 with millimeter accuracy.

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1 Background

The TDC7201 is targeted for use with ultrasonic, LIDAR, and SONAR equipment for time of flight applications. It has two built-in Time-to-Digital Converters (TDCx, x = 1, 2) that perform independently the function of a stopwatch to measure time between a single event (edge on START pin) and multiple subsequent events (edges on STOP pin). Each TDCx has an internal self-calibrated time base that is used to measure time with resolution in the order of 55ps. Self-calibration compensates for drift over time and temperature and enables time-to-digital conversion accuracy in the order of picoseconds. A summary of the TDCx functionality is shown in the Figure 1 and a block diagram of the TDC7201 is shown in Figure 2.

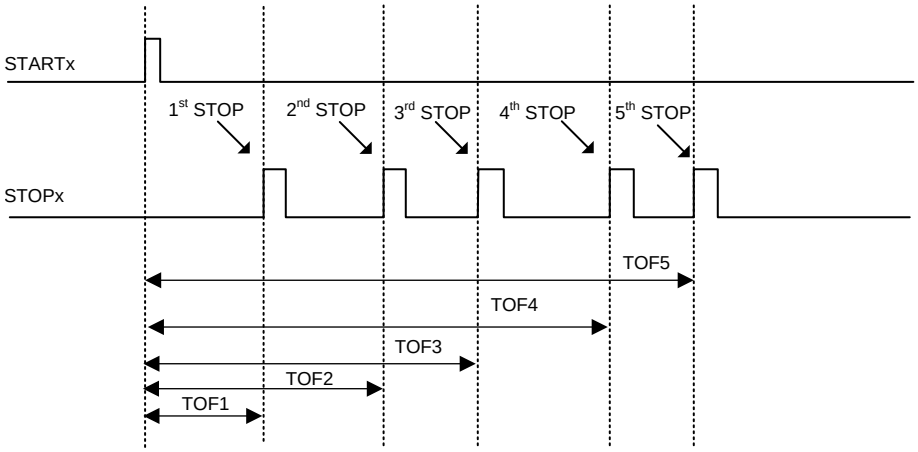

Figure 1. TDCx Measurement Summary

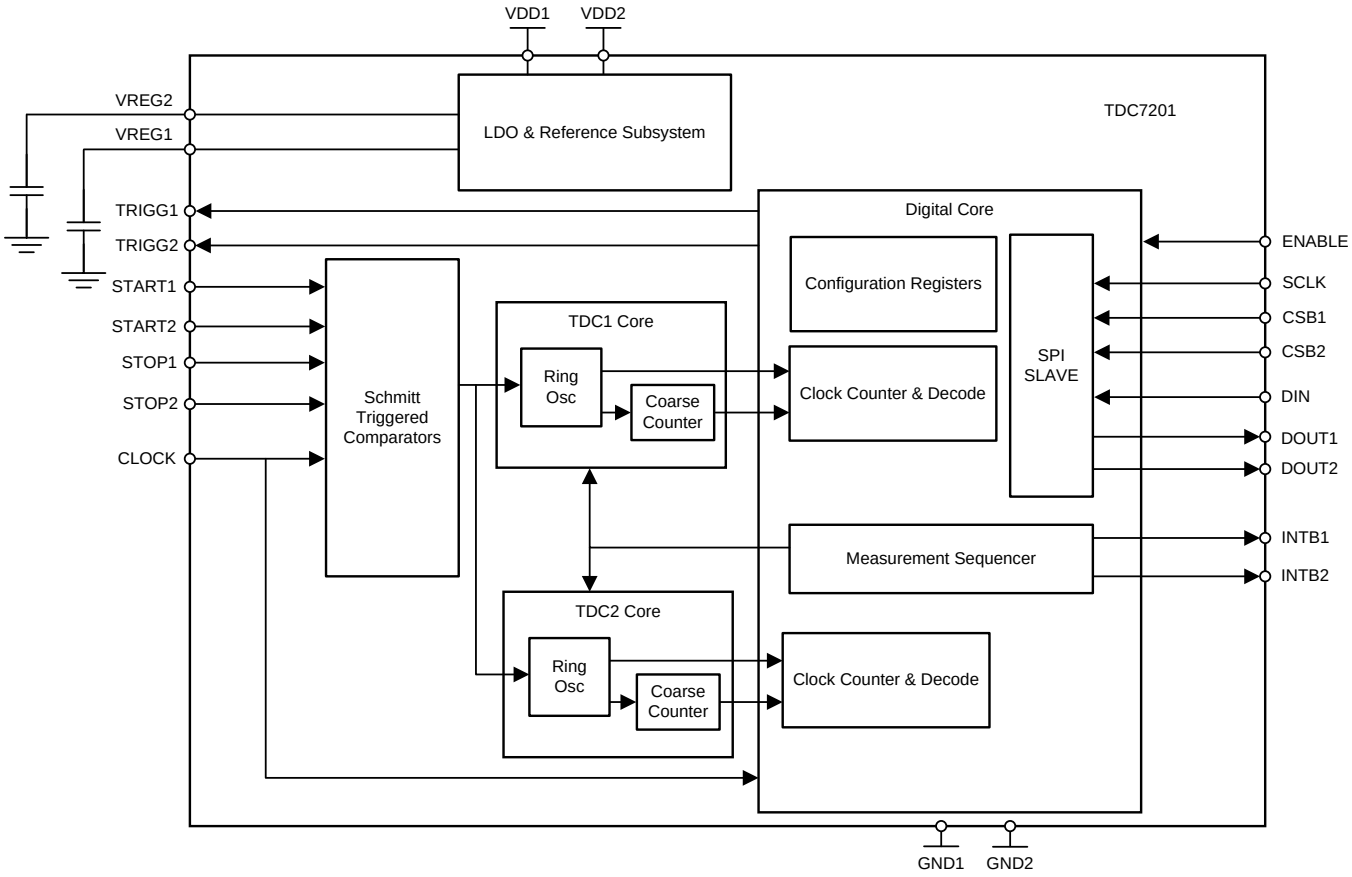

Figure 2. TDC7201 Block Diagram

Each TDCx of the TDC7201 has two measurement modes: Measurement Mode 1 and Measurement Mode 2. The choice of mode is to be based on the duration of time to be measured by the device.

1.1 Measurement Mode 1

In measurement mode 1, as shown in Figure 3, each TDCx of the TDC7201 performs the entire counting from STARTx to the last STOPx using its internal ring oscillator plus coarse counter. This method is recommended for measuring shorter time durations of <500ns. Using measurement mode 1 for measuring >500ns decreases accuracy of the measurement. The minimum time measurable in measurement mode 1 is 12ns.

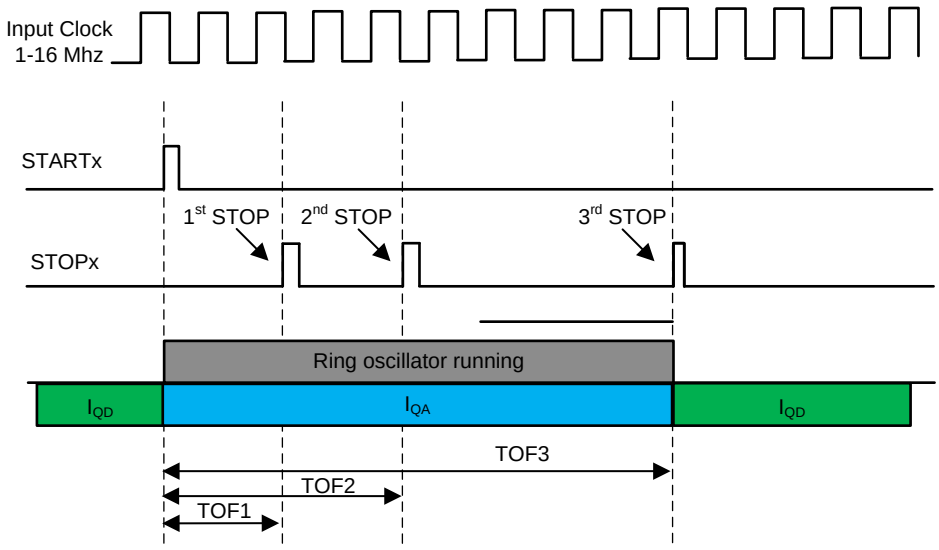

Figure 3. TDCx Measurement Mode 1

1.2 Measurement Mode 2

In measurement mode 2, the internal ring oscillator of each TDC of the TDC7201 is used only to count fractional parts of the total measured time. As shown in Figure 4, the internal ring oscillator starts counting from when it receives the STARTx signal until the first rising edge of the CLOCK. Then, the internal ring oscillator switches off, and the Clock counter starts counting the clock cycles of the external CLOCK input until a STOPx pulse is received. The internal ring oscillator again starts counting from the STOPx signal until the next rising edge of the CLOCK.

This method is recommended for measuring long time durations and can only be used when the time between STARTx and STOPx is a minimum of 2 cycles of the external CLOCK. As the TDC7201 device has a maximum clock frequency of 16MHz, the minimum time measurable in measurement mode 2 is 125ns.

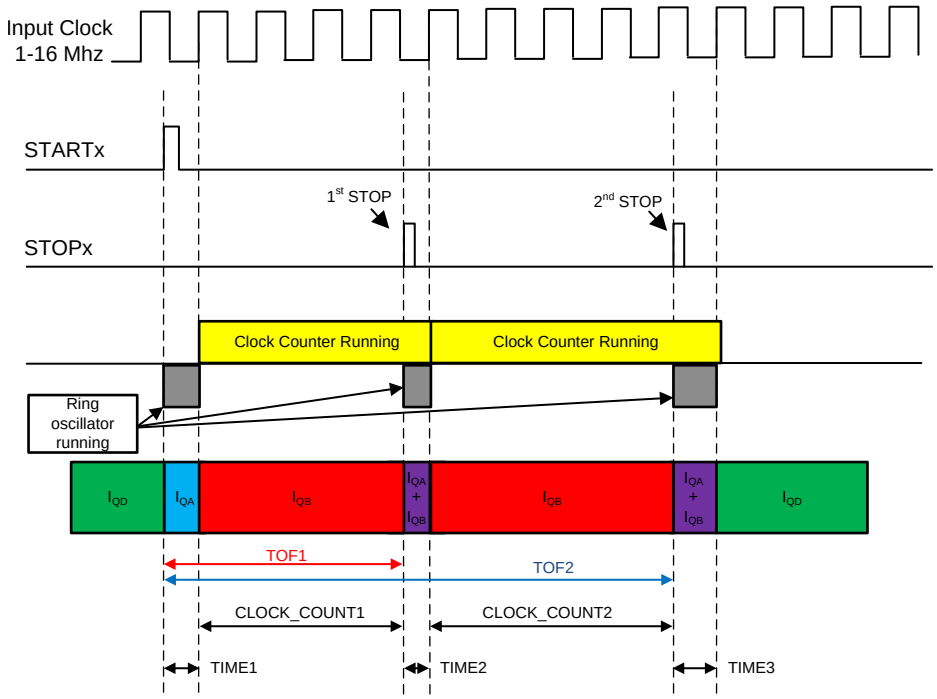

Figure 4. TDCx Measurement Mode 2

2 TDC7201 Short Time Measurements

The minimum time measurable in measurement mode 1 is 12ns. It is feasible to do measurements down to 0.25ns using the two built-in TDCs of TDC7201 in what is called combined measurement mode. In combined measurement mode, START1 and START2 are connected together:

- A common REFERENCE_START signal is applied to START1 and START2 at least 12ns before occurrence of actual Start and Stop signals
- TOF Start (LIDAR_START) signal is connected to STOP1
- TOF Stop (LIDAR_STOP) signal is connected to STOP2
- Two time periods T1 (REFERENCE_START to LIDAR_START) and T2 (REFERENCE_START to LIDAR_STOP) are measured and their difference T3 = (T2-T1) is the required time between Start to Stop

An illustration of this combined measurement mode is in Figure 5 and Figure 6. It is necessary that the REFERENCE_START pulse is generated at least 12ns before the LIDAR_START pulse. The REFERENCE_START could be generated by the MCU or by a pulse generator like the Tektronix DTG5078. In the setup shown below, the two TDCs of the TDC7201 make their measurement in parallel. TDC1 measures the time period T1 and TDC2 measures the time period T2.

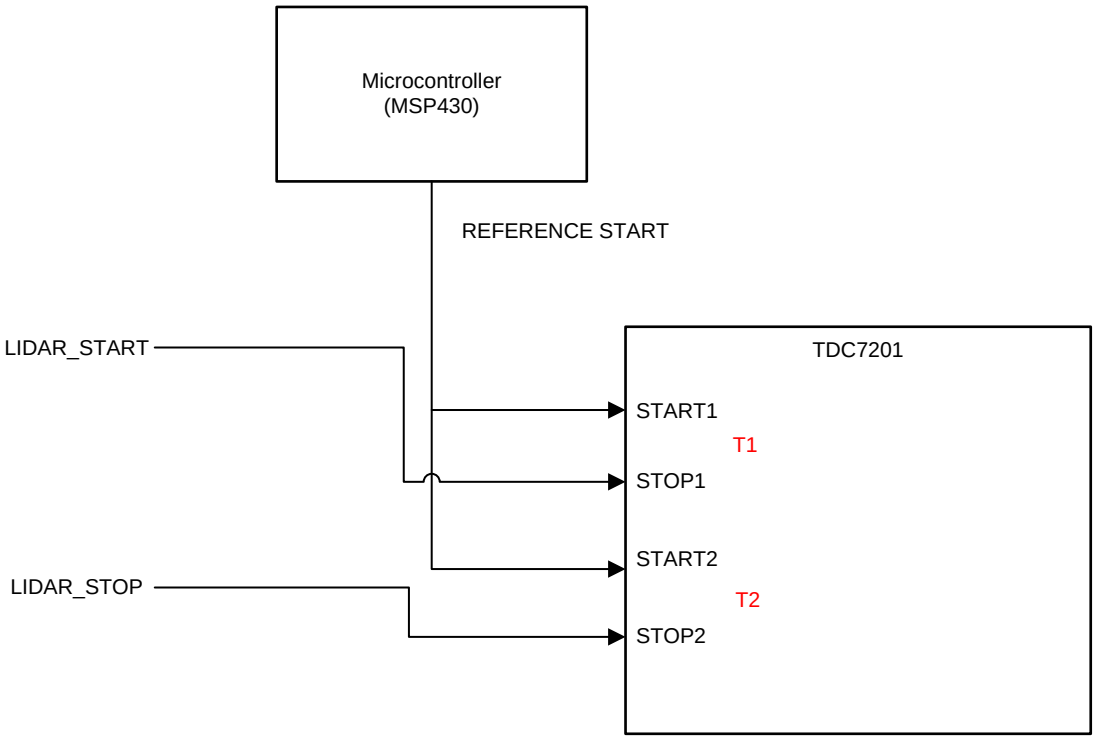

Figure 5. TDC7201 Short Time Measurements Block Diagram

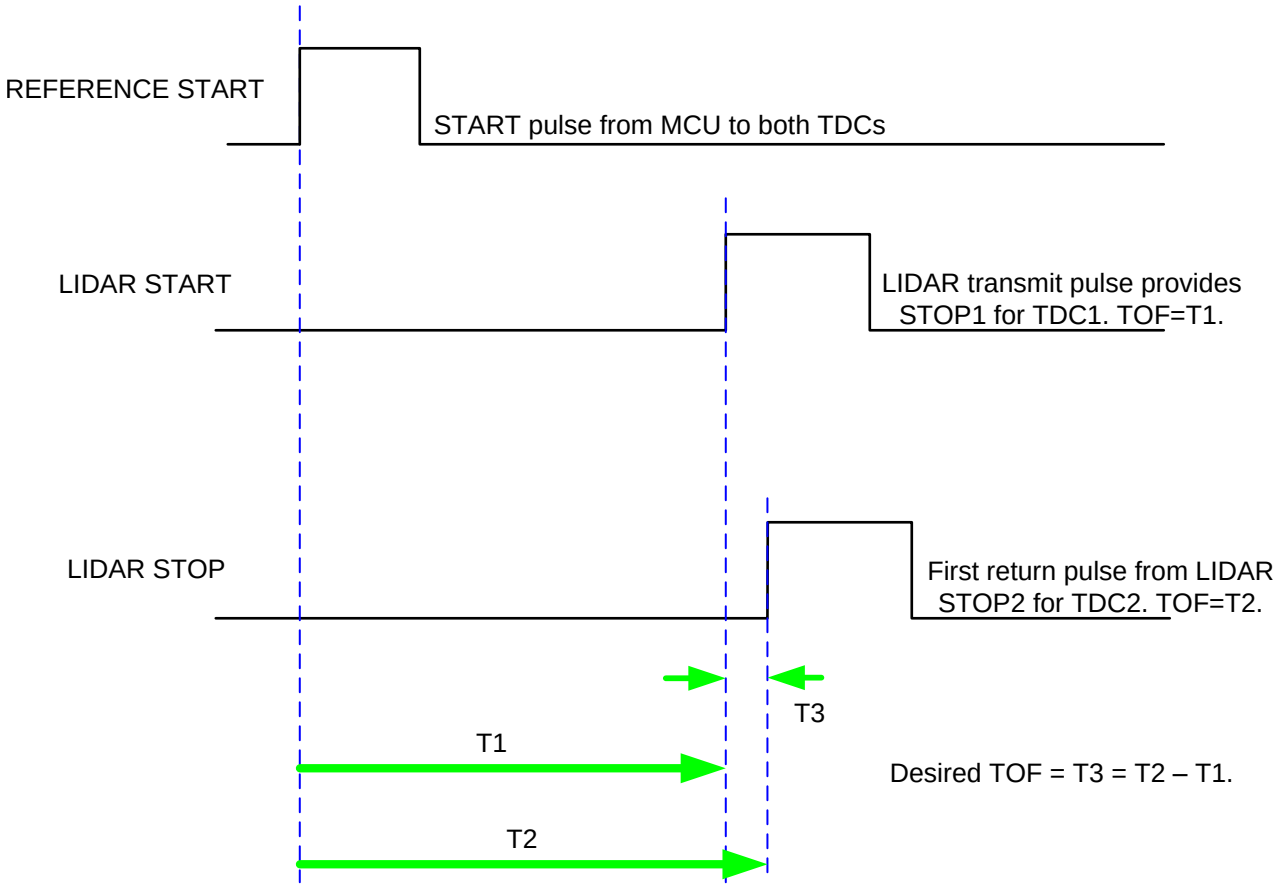

Figure 6. TDC7201 Short Time Measurements Timing Diagram

3 Test Setup

Figure 7shows a block diagram of the test setup. A Tektronix Data Timing Generator DTG5078 and a TDC7201EVM along with MSP430F5529 Launch Pad is used to demonstrate short time measurements. The DTG5078 is used to generate the REFERANCE_START, LIDAR_START and LIDAR_STOP signals following a DTG trigger from the MSP430. The REFERENCE_START signal is applied to the SMA connector labeled “COMMON_START (J3)” on the TDC7201EVM which is connected to TDC7201 START1 and START2 inputs. Following two changes are needed to the TDC7201EVM to use COMMON_START (J3):

- Populate zero ohm resistors R11 and R12
- Remove R2 and R9

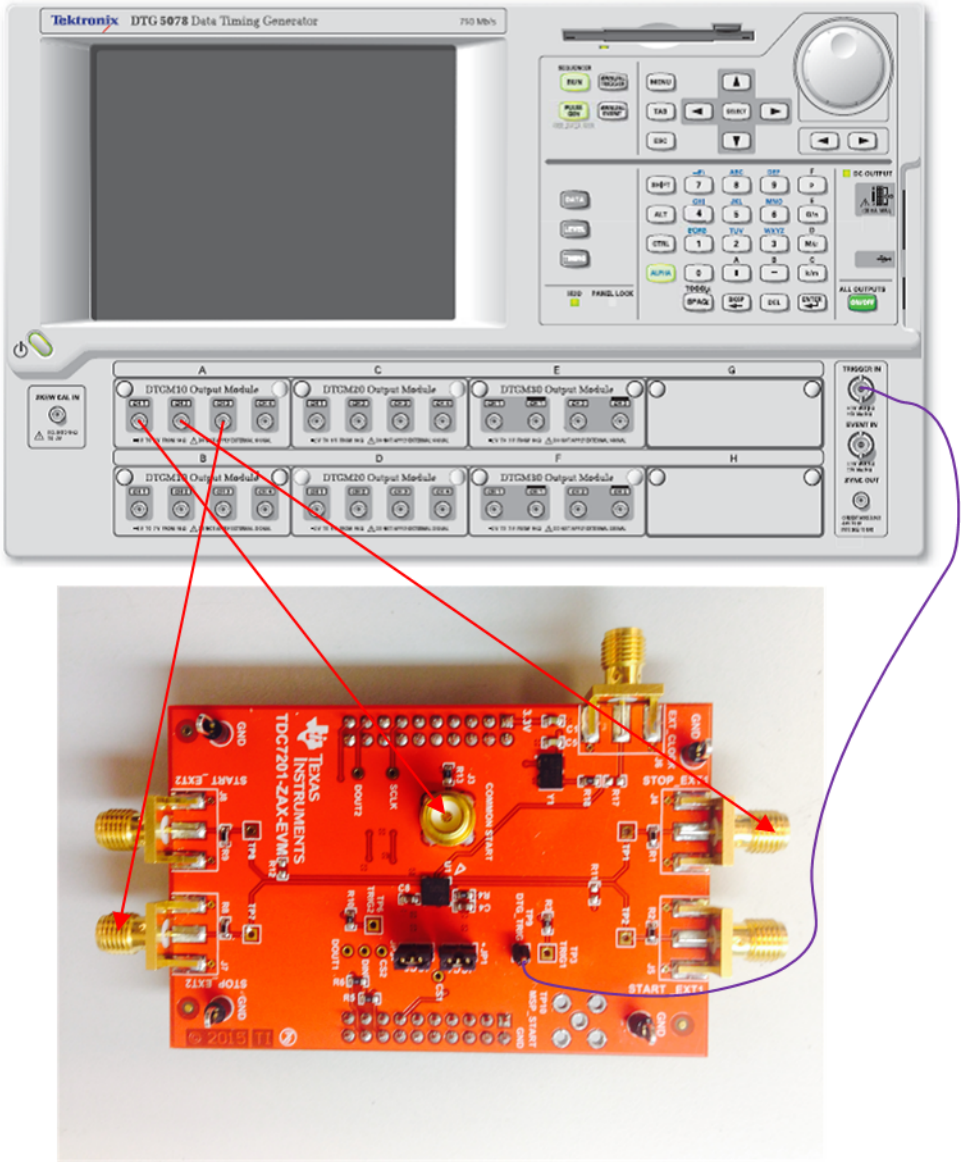

Figure 7. DTG5078 Based Test Setup

An oscilloscope picture of the DTG5078 generated signals is shown in Figure 8. Channel 1 (Blue) represents the REFERENCE_START signal while Channel 2 (Pink) and Channel 3 (Green) represents the LIDAR_START and LIDAR_STOP signals.

Note LIDAR_START is generated 12ns after the REFERENCE _START signal. The start to stop delay for TDC7201 to measure is set as 0.25ns (Δ time period). A screen capture of the TDC7201EVM GUI registers setup for TDC1 and TDC2 are shown in Figure 9 and Figure 10. A screen capture of the TDC7201EVM GUI graph measurement result is shown in Figure 11.

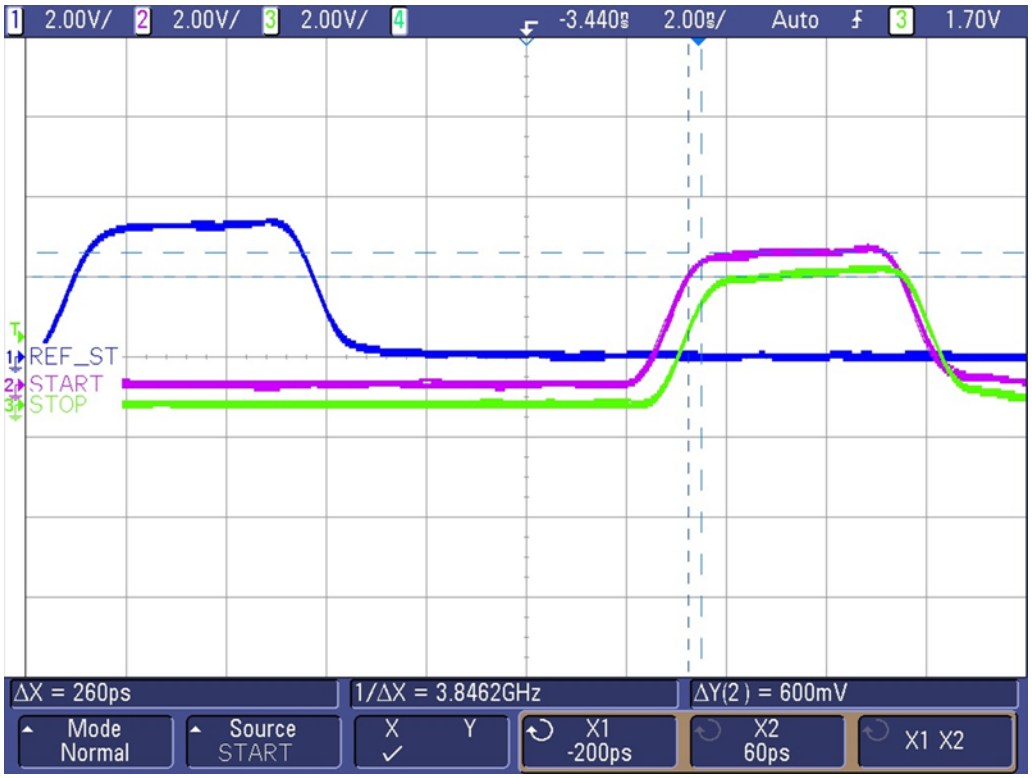

Figure 8. DTG5078 Generated Test Signals For Interleaved Short Time Measurements

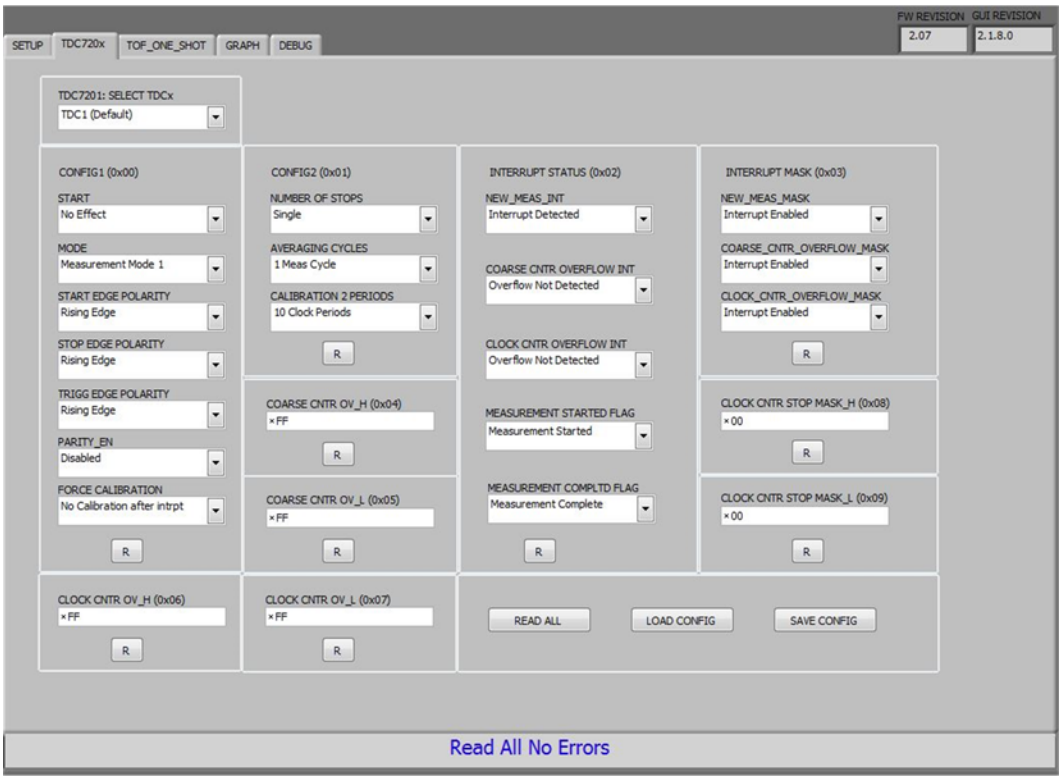

Figure 9. TDC1 Register Setup

Figure 10. TDC2 Register Setup

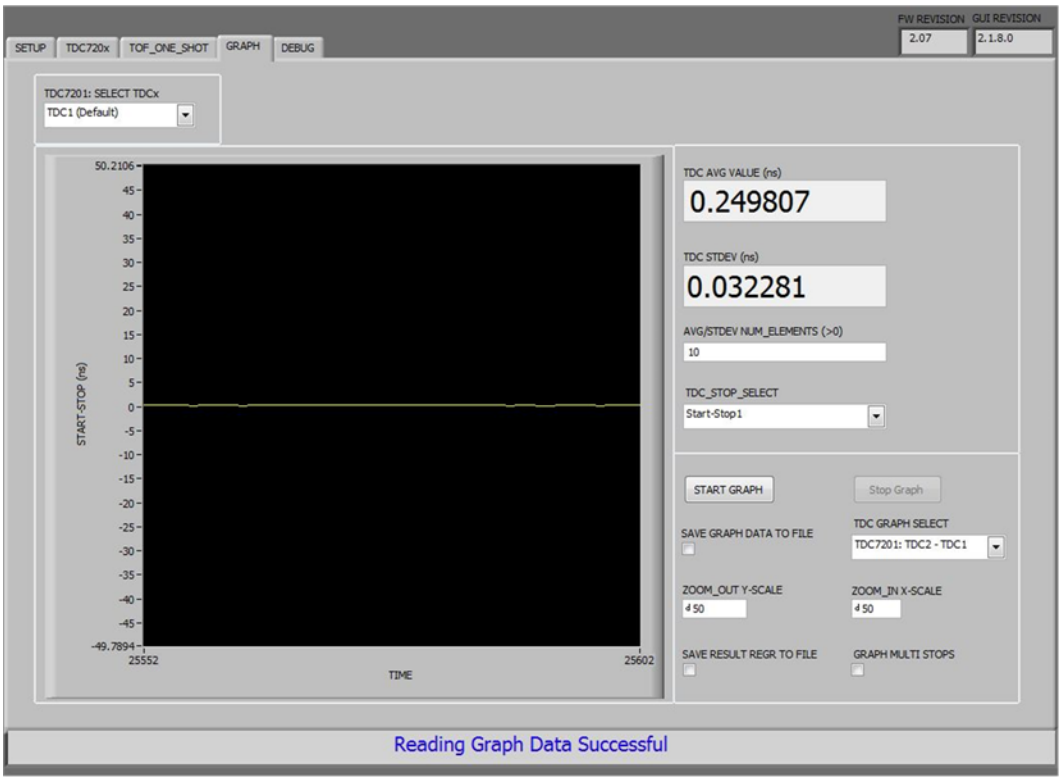

Figure 11. TDC7201 Short Time Measurement Graph Data

4 Test Results

Figure 12 to Figure 17 show the raw TOF measurement data of TDC7201 in combined measurement mode and its equivalent distance for TOF durations of 0.25ns, 0.5ns and 1ns. Over 50,000 samples are captured and plotted. A 128x running average of the raw samples is also shown. In summary, raw data shows an absolute worst case deviation of 60ps (0.9cm) while 128x running average data shows an absolute worst case deviation of 6.5ps (1mm).

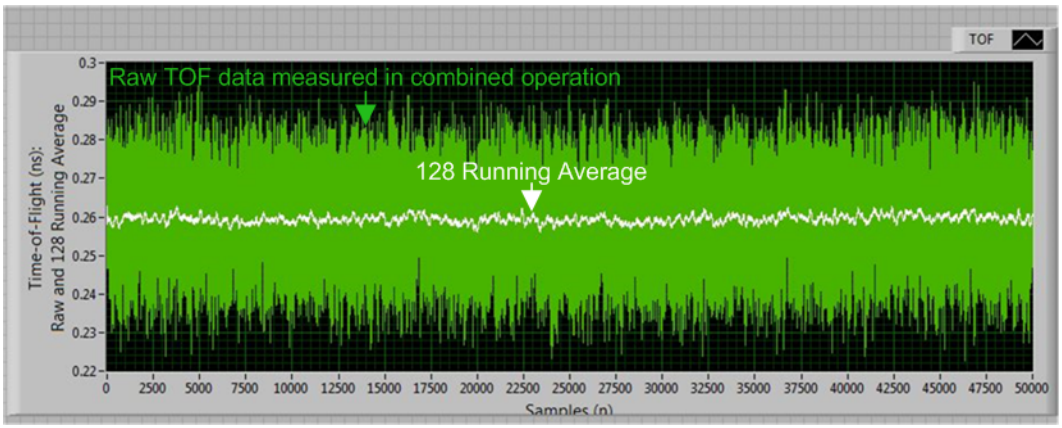

Figure 12. TDC7201 Combined Measurement Data for TOF=0.25ns: Raw and 128x Running Average

Figure 13. TDC7201 Combined Measurement Data for TOF=0.25ns: Equivalent Distance Raw and 128x Running Average

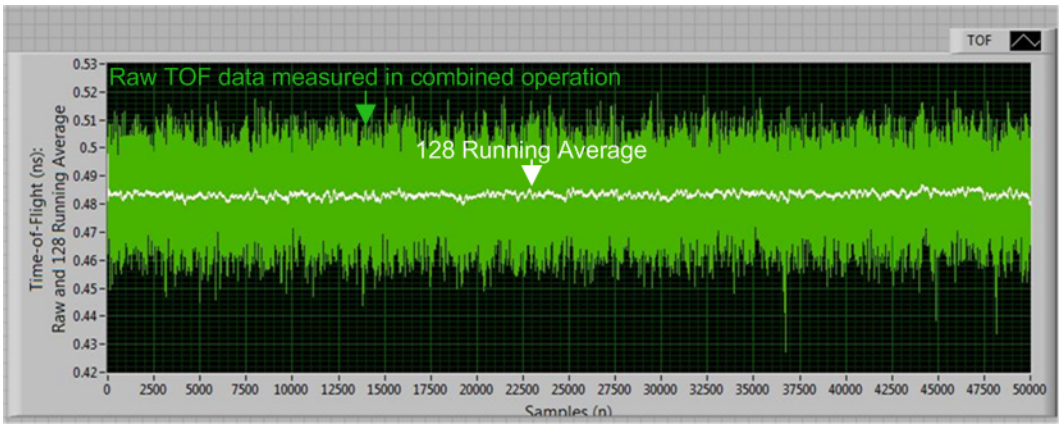

Figure 14. TDC7201 Combined Measurement Data for TOF=0.5ns: Raw and 128x Running Average

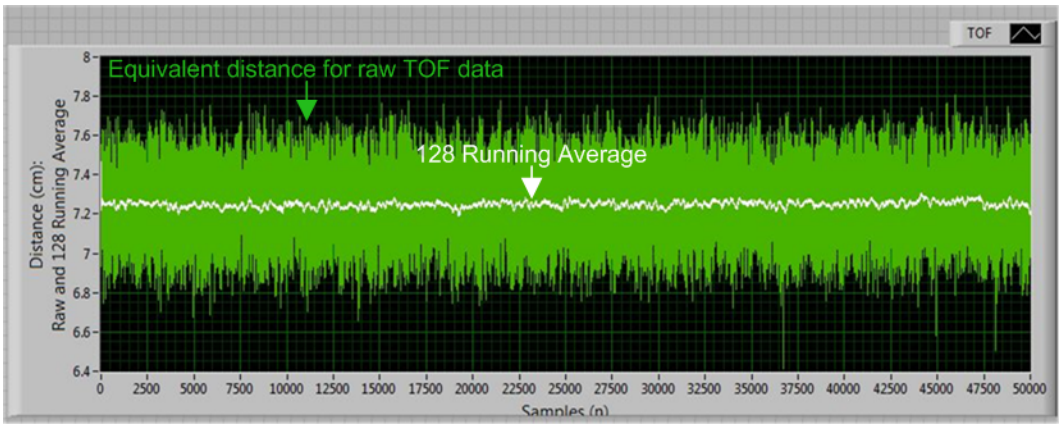

Figure 15. TDC7201 Combined Measurement Data for TOF=0.5ns: Equivalent Distance Raw and 128x Running Average

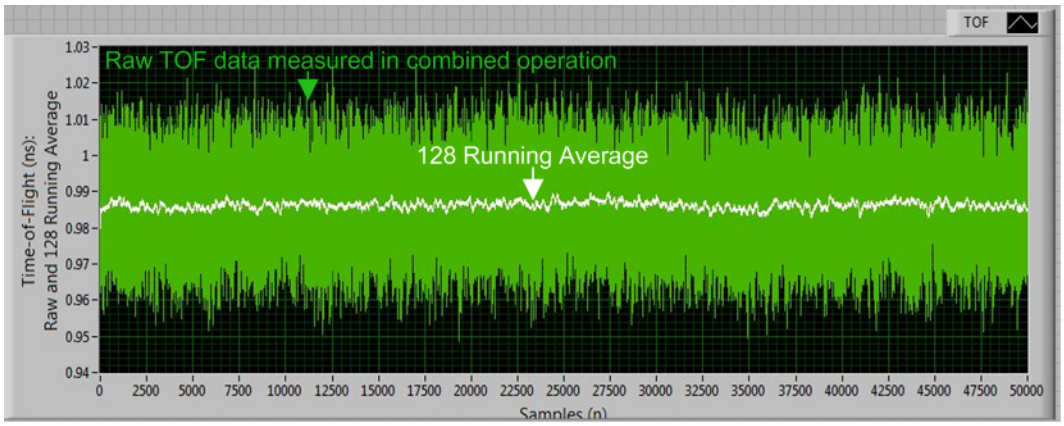

Figure 16. TDC7201 Combined Measurement Data for TOF=1.0ns: Raw and 128x Running Average

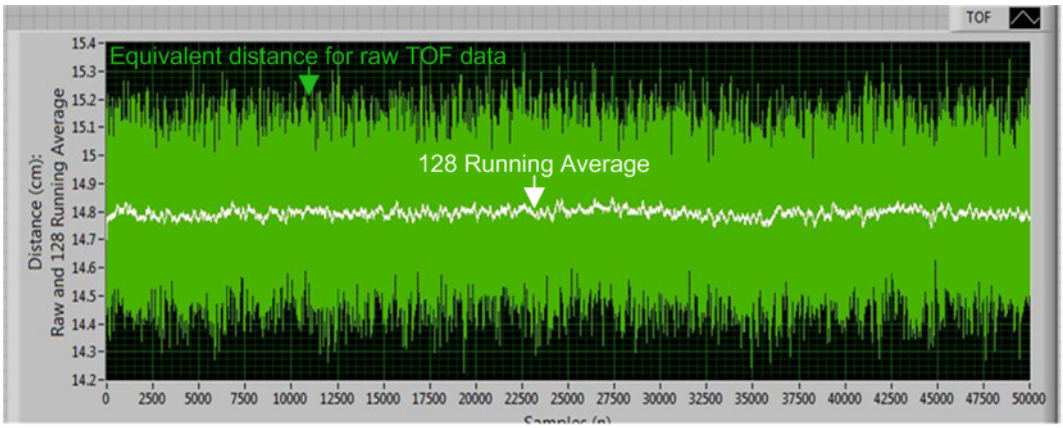

Figure 17. TDC7201 Combined Measurement Data for TOF=1.0ns: Equivalent Distance Raw and 128x Running Average

5 References

1. TDC7201 Data Sheet (http://www.ti.com/lit/ds/symlink/tdc7201.pdf)
2. TDC7201 Evaluation Module (http://www.ti.com/tool/tdc7201-zax-evm)

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