Application Report
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Interleaved Short Time Measurements Using TDC7200

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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 distance traveled. Speed of light in air is multitudes of orders higher than the speed of sound waves in air hence the total distance moved by light waves is much higher during the time frame. For very short distance measurements (<2 meters), time of flight is in the range of 0ns to 12ns. The objective of this application note is to describe a method for measuring time periods less than 12ns using TDC7200.

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1 Background

The TDC7200 is a Time to Digital Converter (TDC) that performs the function of a stopwatch. It is used to measure time between a single event (edge on START pin) and multiple subsequent events (edges on STOP pin). The device 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 functionality is shown in Figure 1 and a block diagram of the TDC7200 is shown in Figure 2.

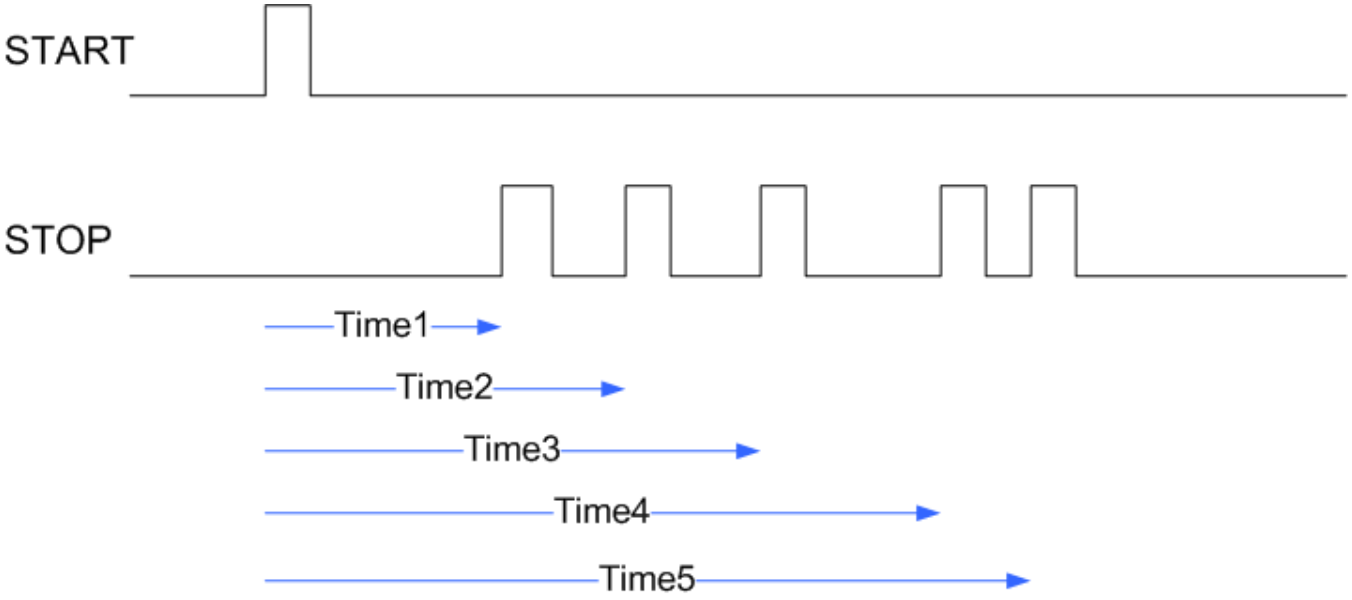

Figure 1. Measurement Summary

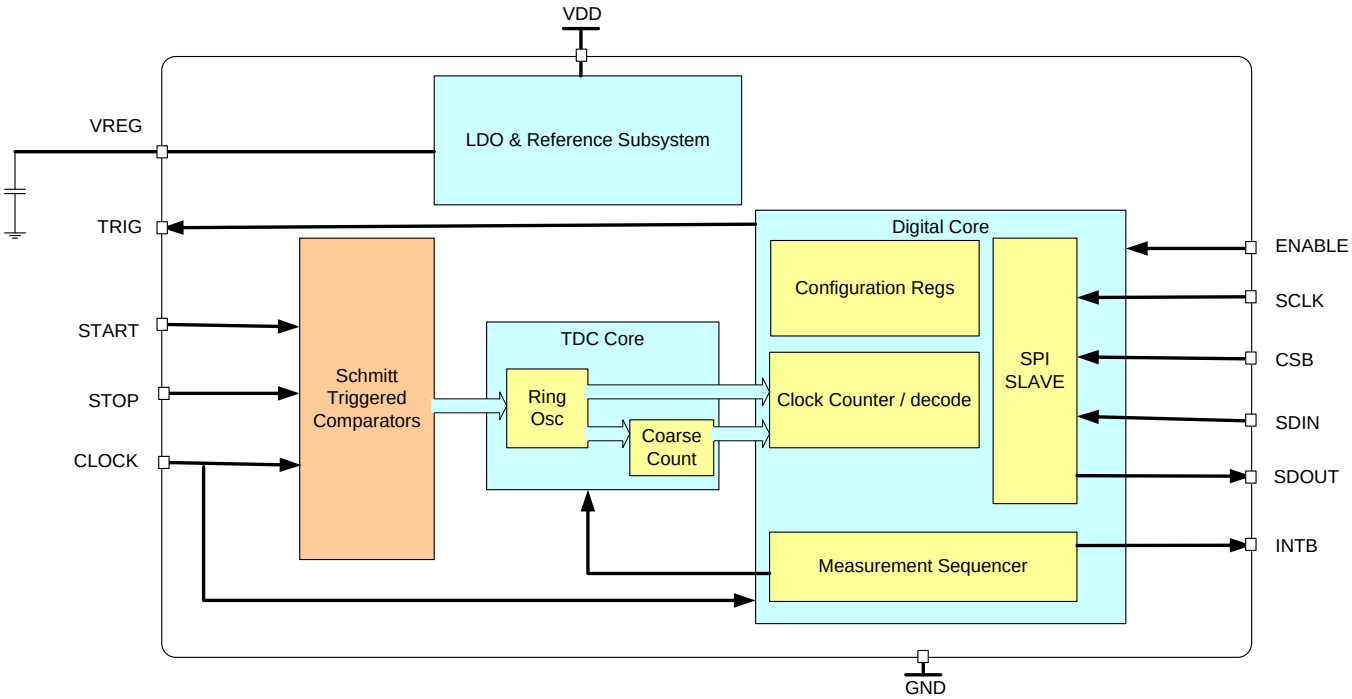

Figure 2. Functional Block Diagram

The TDC7200 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, the TDC7200 performs the entire counting from START to the last STOP 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.

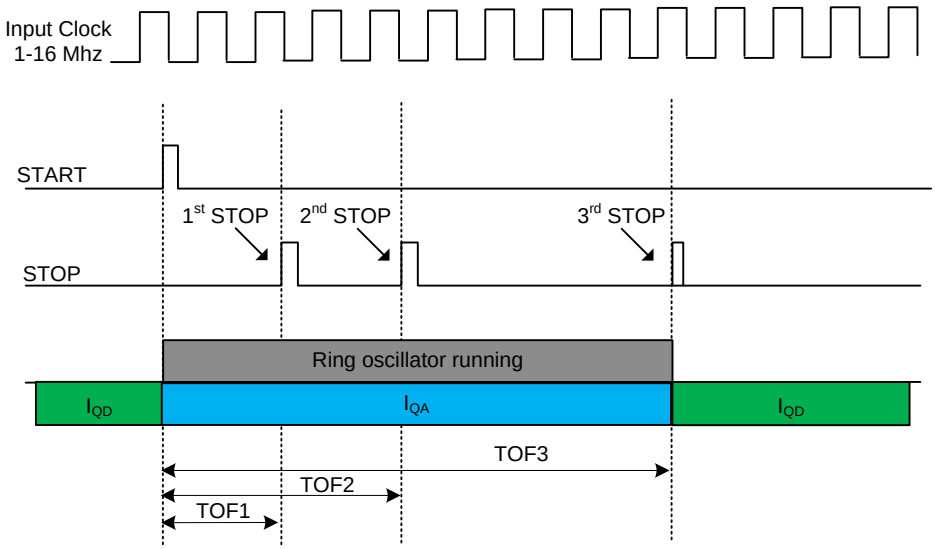

Figure 3. Measurement Mode 1

1.2 Measurement Mode 2

In measurement mode 2, the internal ring oscillator of the TDC7200 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 START 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 STOP pulse is received. The internal ring oscillator again starts counting from the STOP 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 START and STOP is a minimum of 2 cycles of the external CLOCK. As the TDC7200 device has a maximum clock frequency of 16MHz, the minimum time measurable in measurement mode 2 is 125ns.

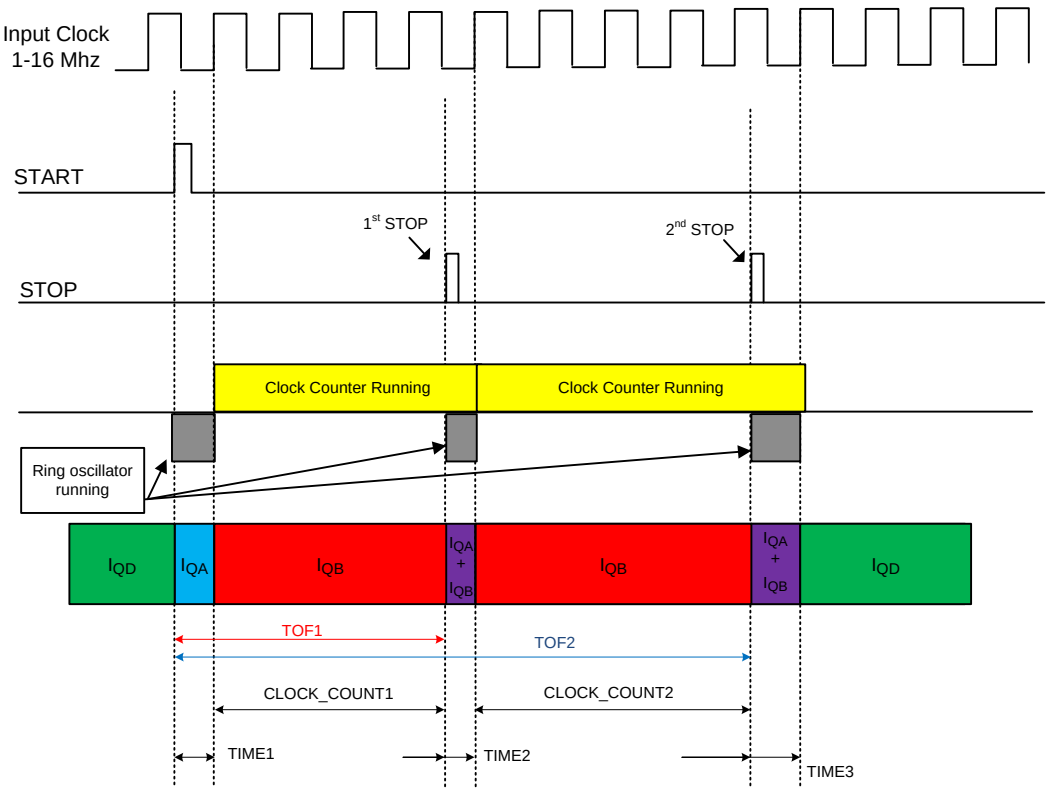

Figure 4. Measurement Mode 2

2 TDC7200 Interleaved Short Time Measurements

The minimum time measurable in measurement mode 1 is 12ns. It is feasible to do measurements down to 0ns using a single TDC7200 if the measurement can be repeated. Assuming the measured time changes slowly, if two measurements are done in a 10us period, the measured time will remain approximately the same.

Using a reference pulse from the MCU, the first measurement captures the time from the reference to the START signal and the second measurement captures the time from the reference to the STOP signal. Assuming the time of flight has not changed in the 10us period, the difference between the two measurements gives time of flight. An illustration of this interleaved measurement approach is shown in Figure 5 and Figure 6 below.

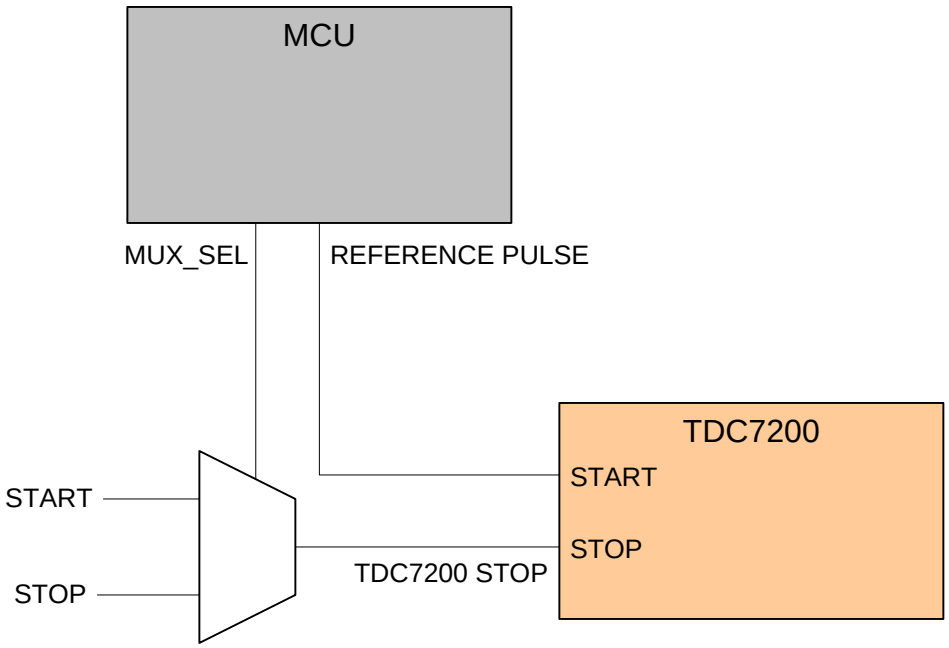

Figure 5. Interleaved Short Time Measurements Block Diagram

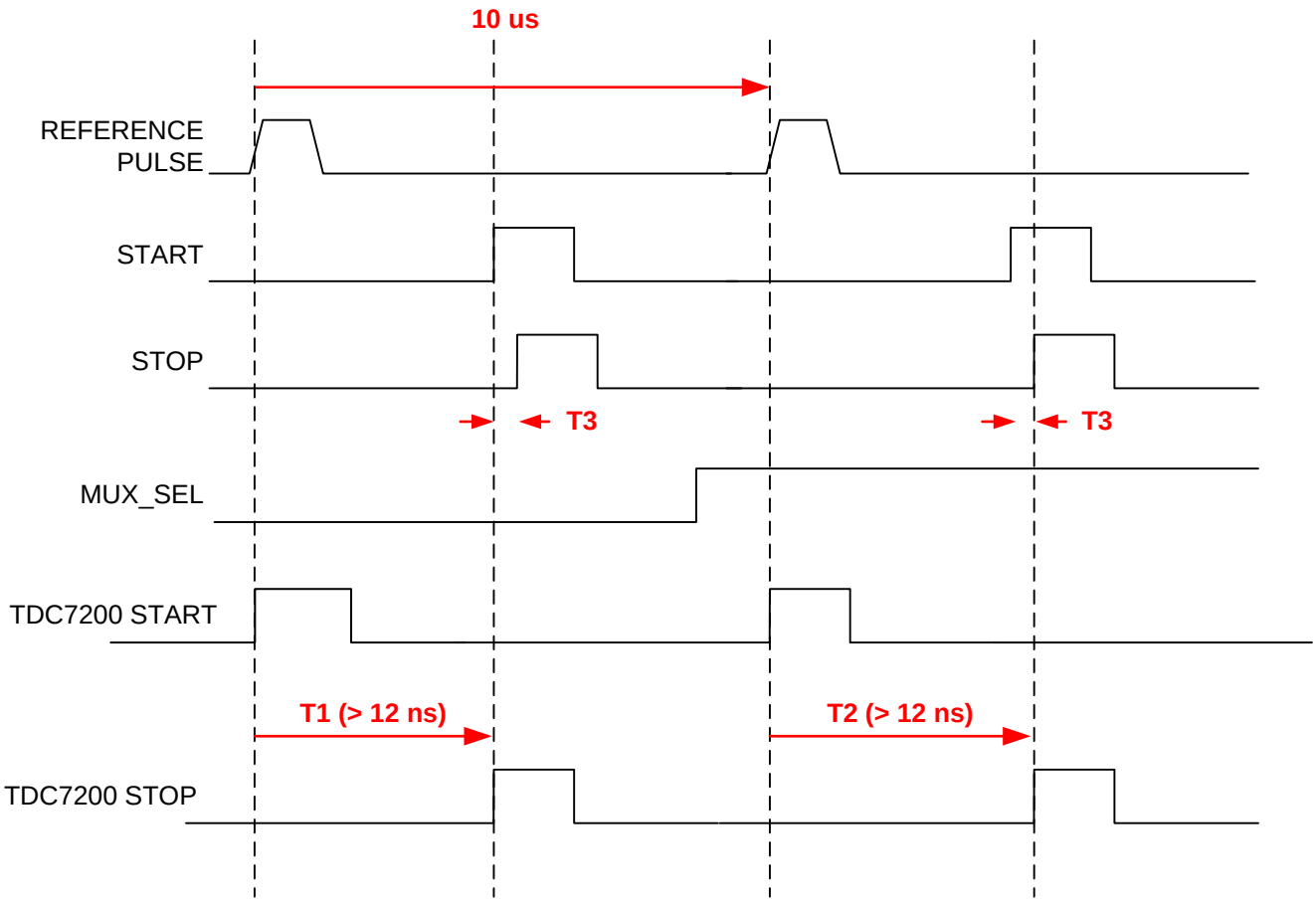

Figure 6. Interleaved Short Time Measurements Timing Diagram

It is necessary that the reference pulse is generated at least 12ns before the START and STOP pulses and also the reference pulse to START duration remains the same between the two interleaved measurements. Reference pulse could be generated either by the MCU or by some other timing circuit. MUX_SEL pin changes state only between measurements and therefore, a high speed mux is not required.

3 Implementation of TDC7200 Interleaved Short Time Measurement

The schematic of a test board to implement the TDC7200 interleaved short time measurement is shown in Figure 7 and a picture of the test board is shown in Figure 8. This board is based on the TDC7200EVM and connects as booster pack to the MSP430 Launch Pad (MSP-EXP430F5529LP). The TDC7200EVM is modified to include the TS3A44159 analog switch.

The TS3A44159 is a bidirectional device that has two sets of two single-pole double-throw switches. The four channels are controlled by two GPIO signals: MUX1_CTRL and MUX2_CTRL. The TS3A44159 switch in its default state connects START_EXT to TDC7200 START and STOP_EXT to TDC7200 STOP. This is the normal operation of the TDC7200 device and can measure time delays up to 12ns.

For interleaved short time measurement less than 12ns, two back to back measurements are done. First measurement is made with MUX1_CTRL and MUX2_CTRL set high. This configuration connects REF_START to TDC7200 START and START_EXT to TDC7200 STOP thereby allowing us to measure REF_START to START_EXT duration. Then a second measurement is made with MUX1_CTRL high and MUX2_CTRL low. This configuration connects REF_START to TDC7200 START and STOP_EXT to TDC7200 STOP thereby allowing us to measure REF_START to STOP_EXT duration. The difference between these two measurements gives the required START_EXT to STOP_EXT time period. The two measurements are repeated within a 10us period so the measurement conditions remain the same. Table 1 below summarizes this mux control configurations.

Table 1. Mux Control for Interleaved Short Time Measurements

MUX1_CTRL	MUX2_CTRL	Measurement Configuration
Low	Low	Default Operation: Connect START_EXT to TDC7200 START and STOP_EXT to TDC7200 STOP. TDC7200 measures START_EXT to STOP_EXT (applicable for > 12ns time measurement)
High	High	Interleaved Measurement 1: Connect REF_START to TDC7200 START and START_EXT to TDC7200 STOP. TDC7200 measures REF_START to START_EXT.
High	Low	Interleaved Measurement 2: Connect REF_START to TDC7200 START and STOP_EXT to TDC7200 STOP. TDC7200 measures REF_START to STOP_EXT. TDC7200 measures REF_START to STOP_EXT.
Low	High	Not used

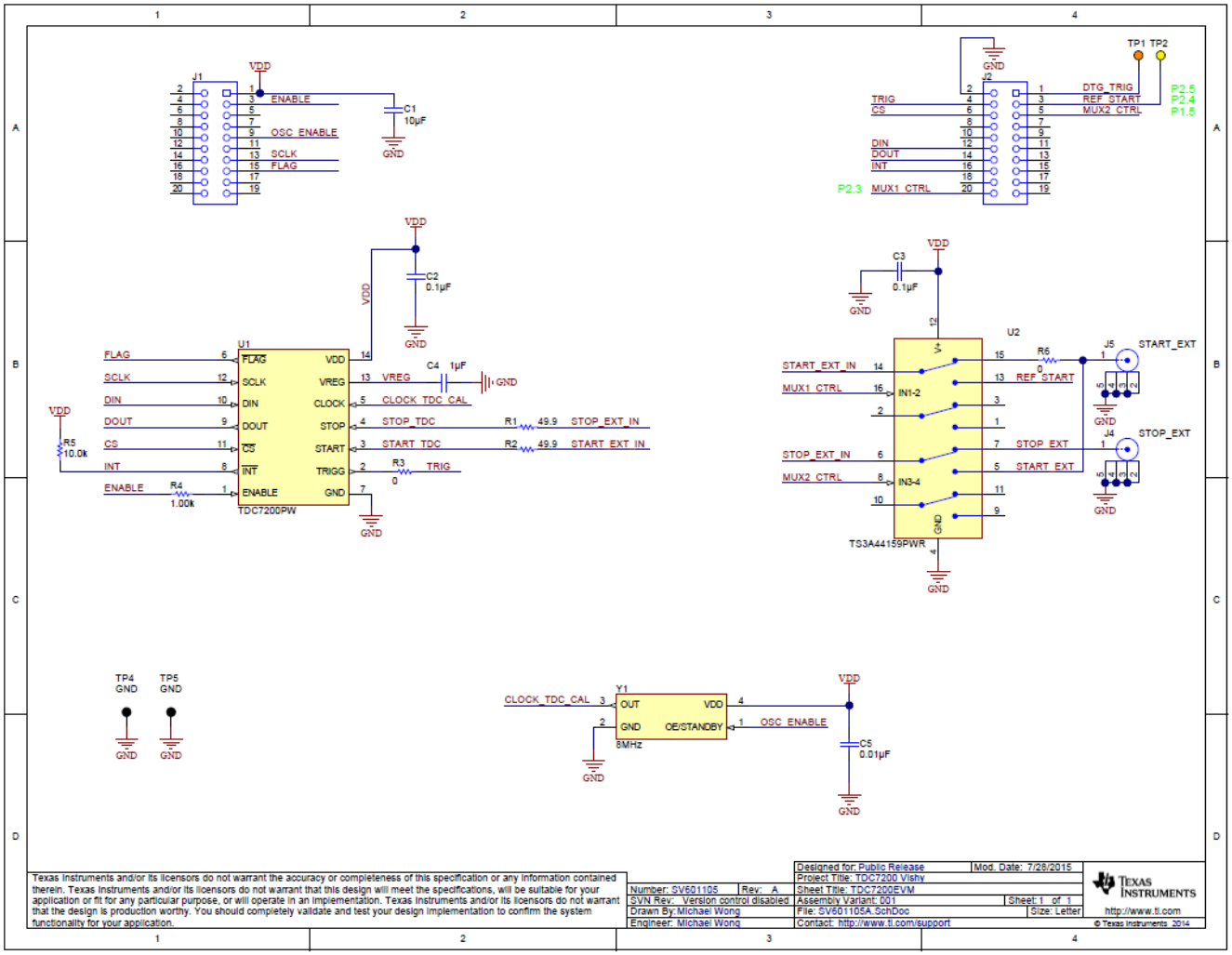

Figure 7. Schematic of Test Board to Implement Interleaved Short Time Measurements

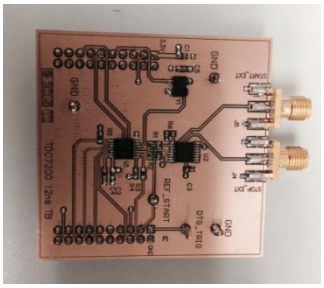

Figure 8. Test Board to Implement Interleaved Short Time Measurements

TDC7200EVM GUI and Firmware are updated to demonstrate interleaved short time measurements with TDC7200. In the “DEBUG” tab of the TDC7200EVM GUI, there’s a new option called “TDC7200 Measure LT12ns” to support this as highlighted in Figure 9.

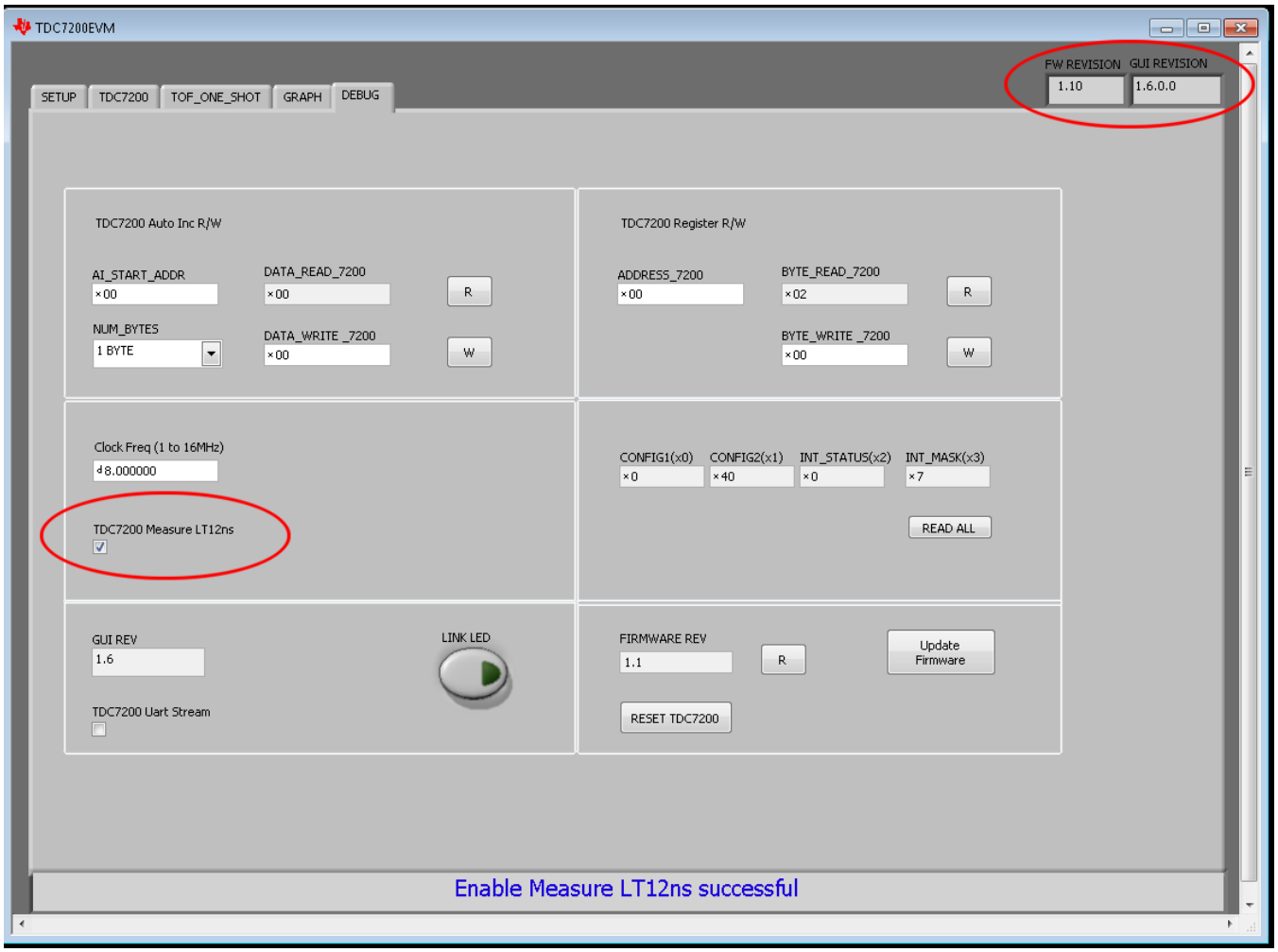

Figure 9. TDC7200EVM GUI Enhanced To Support Interleaved Short Time Measurements

4 Test Setup

A block diagram of the test setup is shown in Figure 10. Tektronix Data Timing Generator DTG5078 is used to generate the REF_START, START_EXT and STOP_EXT signals following a DTG trigger from MSP430.

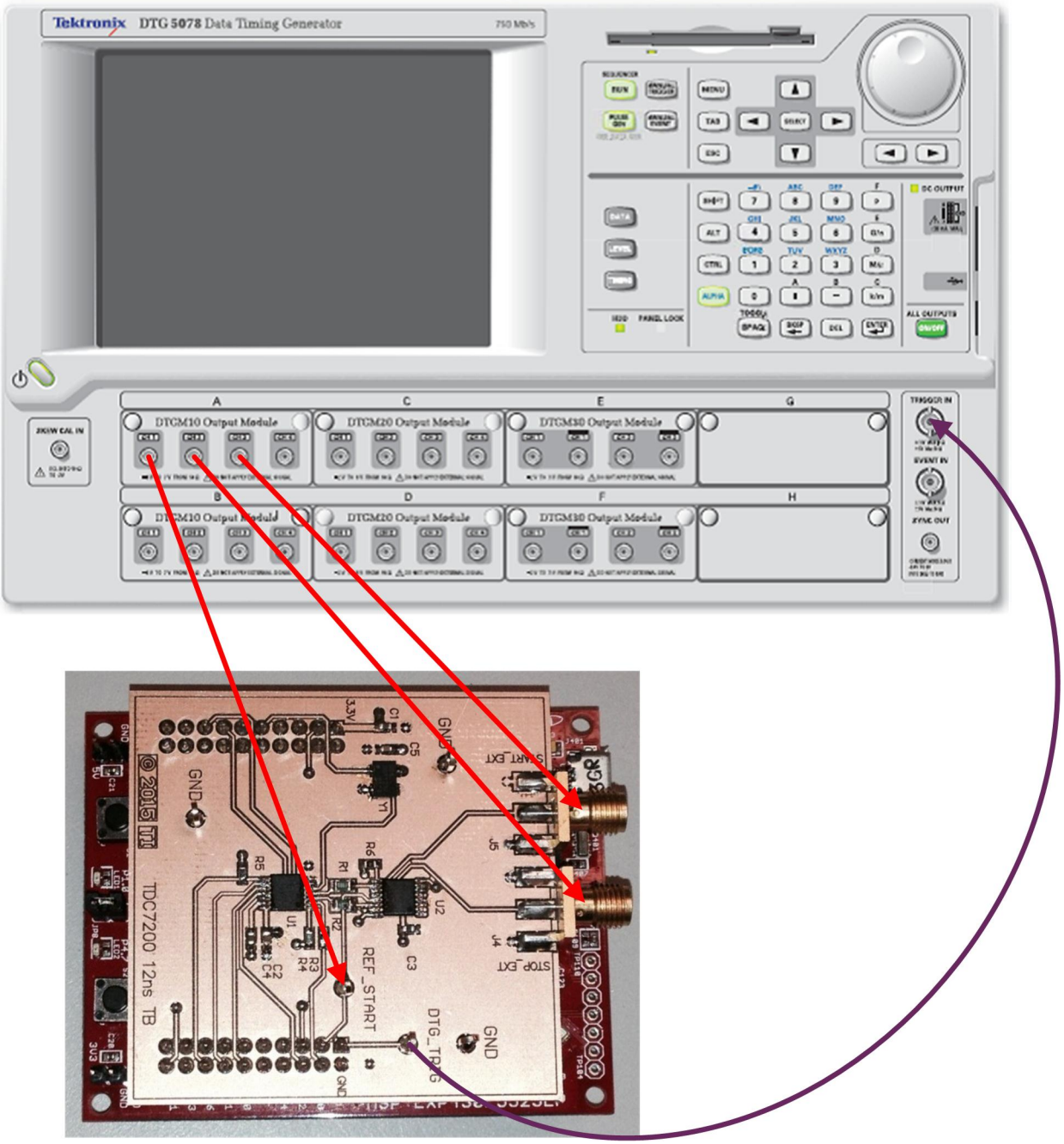

Figure 10. DTG5078 Based Test Setup

An oscilloscope picture of the DTG5078 generated signals is shown in Figure 11. Channel 4 (Green) represents the REF_START signal while Channel 2 (Teal) and Channel 3 (Pink) represents the START_EXT and STOP_EXT signals.

START_EXT is generated 20ns after the REF_START signal. The start to stop delay for TDC7200 to measure is set as 2ns (Δ time period). A screen capture of the TDC7200EVM GUI with the displayed measurement result is shown in Figure 12. With this interleaved short time measurement, the TDC7200 is capable of measuring time of flight durations down to 0ns.

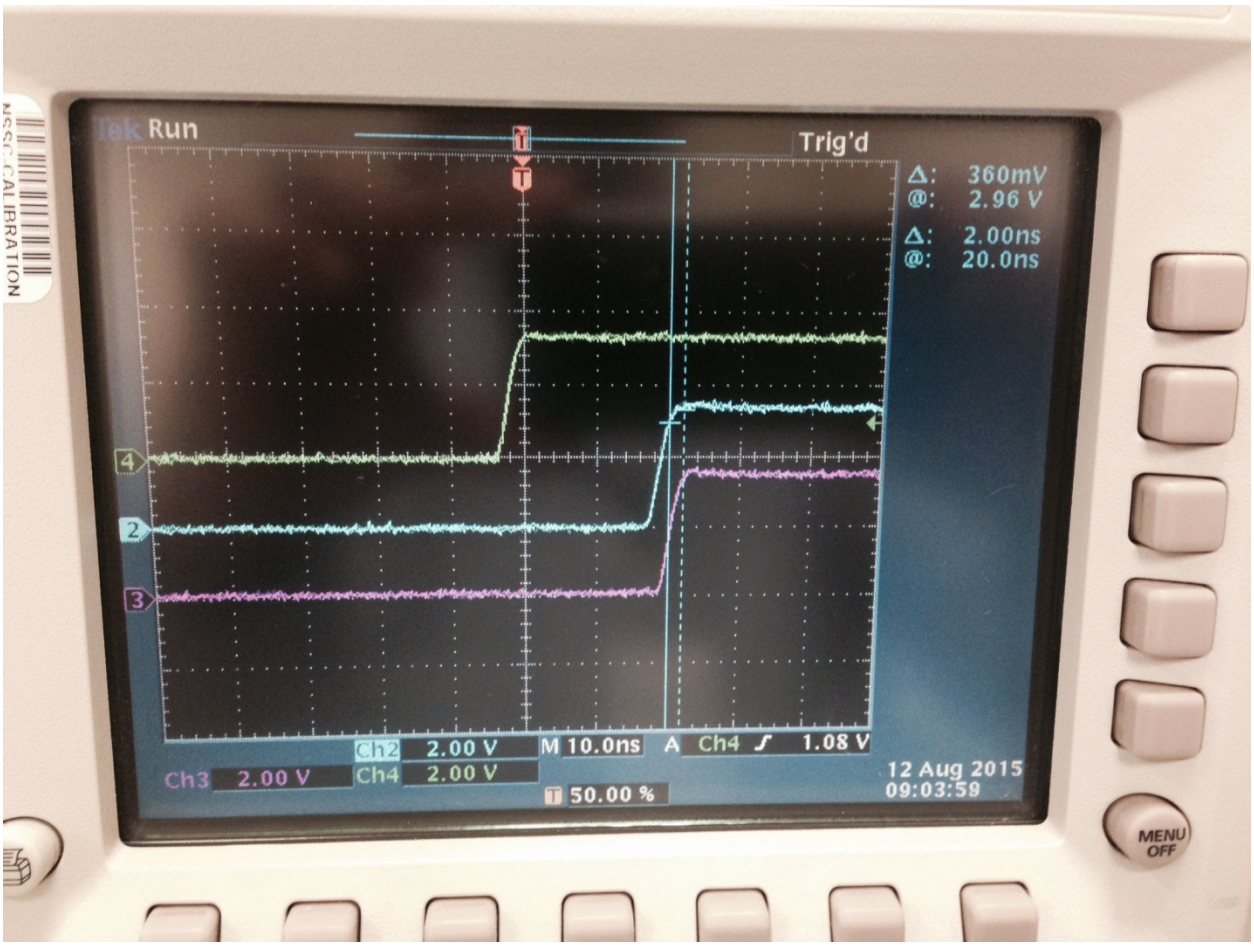

Figure 11. DTG5078 Generated Test Signals for Interleaved Short Time Measurements

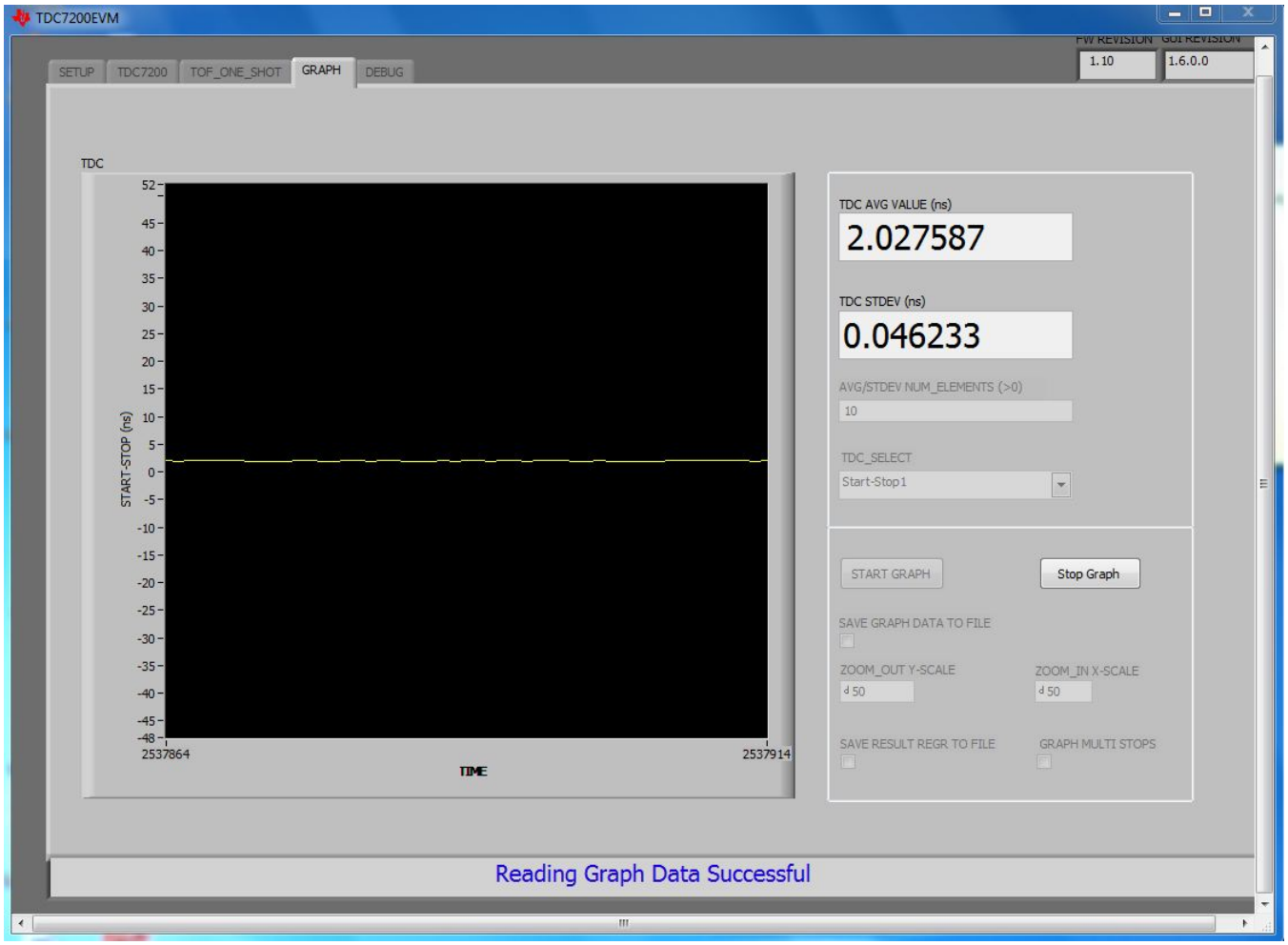

Figure 12. TDC7200 Interleaved Short Time Measurement Results

5 References

1. TDC7200 Data Sheet (http://www.ti.com/lit/ds/symlink/tdc7200.pdf)
2. TDC7200 Evaluation Module (http://www.ti.com/tool/tdc7200evm)
3. TS3A44159 Data Sheet (http://www.ti.com/lit/ds/symlink/ts3a44159.pdf)

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