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UNO-TDC datasheet

Specifications

The UNO-TDC is a Time to Digital Converter (TDC) that performs the function of a stopwatch and measures the elapsed time between a START pulse and up to five STOP pulses. START and STOP inputs are CMOS logic compatible and are 50ohm terminated.

The UNO-TDC has a measurement range of 14ns to 3926ns, and a dead time of 100μs between two consecutive measurements. UNO-TDC must always receive a STOP signal because it does not feature a STOP timeout. The measurement resolution is 55ps and the error varies according to the measurement range as described in the “UNO-TDC characterization” paragraph. As a “rule of thumb” 1% error could be considered on all ranges.

The data is not saved but continuously streamed to the computer on the serial port. The serial interface is set to no parity bit and baud rate 38400. To start the acquisition the UNO-TDC must receive a random character on the serial interface.

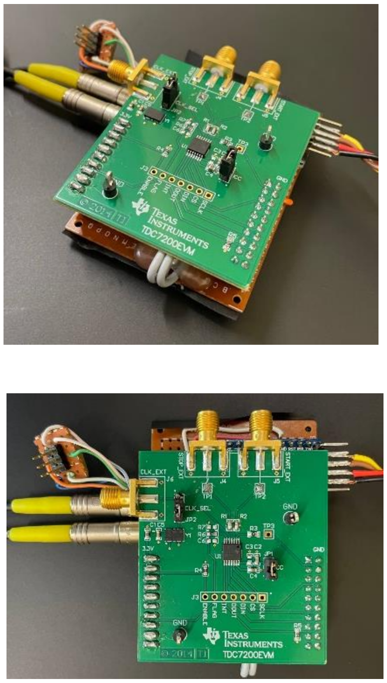


Fig. 6.1: TDC7200EVM evaluation module is connected to a circuit board, on which an Arduino mini, a 3.3V regulator, a voltage level shifter and the start and stop inputs (on the left) are hand-soldered.

1 Theory of operation

The UNO-TDC is built around a Texas Instruments tdc7200[6.1] integrated circuit, and an Arduino Uno. The tdc7200 is used as a time to digital converter and the Arduino as an interface (and data buffer) between the computer and the tdc7200. A complete electronic scheme is available in the appendix.

To start a new measurement the Arduino requests it by sending a “new measurement” control sequence to the tdc7200; any START or STOP signals received before the “new measurement” request will be ignored. The tdc7200 begins counting on the rising edge of the START signal.

The UNO-TDC must receive a STOP signal before 3926 ns have elapsed, otherwise it will overflow and reset the counter register TIME1 to 1965 ns (not 0 ns!) and continue to count. Due to the lack of an dedicated overflow output pin on tdc7200 it is not possible to count more than 3926 ns.

After receiving a STOP signal the tdc7200 performs an internal calibration. The resulting calibration factors are stored in tdc7200 internal registers CALIBRATION1 and CALIBRATION2. Now the measurement is complete and the tdc7200 sends a trigger signal to the Arduino, thus starting a reading measurement routine.

The Arduino stores the register data (TIME1, CALIBRATION1 and CALIBRATION2) as raw register values in a circular serial buffer and immediately requests a new measurement. If the buffer is full an error condition is sent to the computer specifying the number of measurements lost. The TDC-UNO continuously streams the raw registers data on the serial port until the serial buffer is empty. The streaming operation does not influence acquisition operation. Due to calibration time and the time needed to harvest the registers data the dead time is 100µs. In fig. 6.2 and 6.3 the synchronization between input signals and communication signals sent between the tdc7200 and the Arduino UNO can be seen.

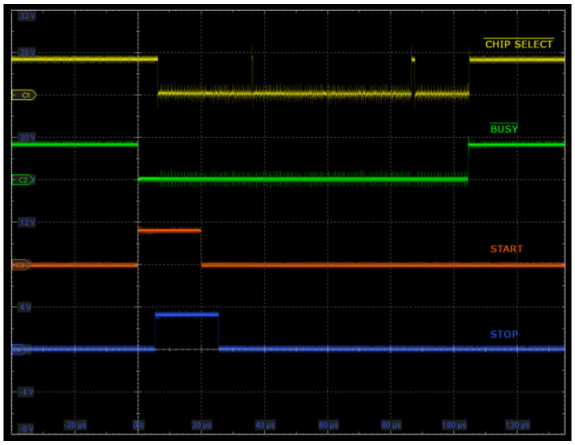


Fig. 6.2: CHIP SELECT (~CS) is low (active) when raw data is being harvested from tdc7200, and when requesting a new measurement. The sum of the active ~CS time inbetween data frames is the dead time due to communication latency between Arduino and tdc7200.
Communication latency deadtime is 100 µs.

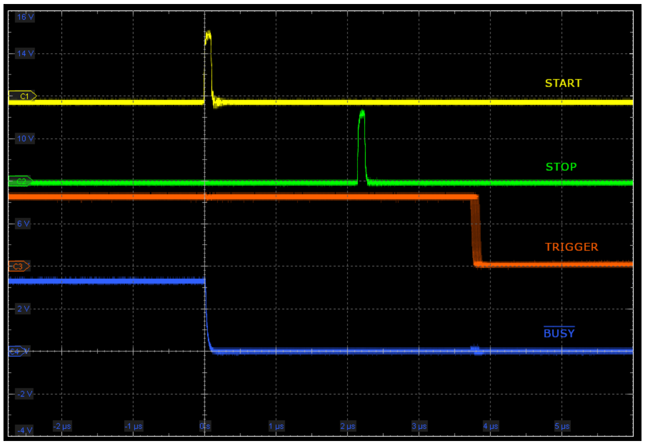


Fig. 6.3: The difference between the rising edge of the STOP signal and the falling edge of the TRIGGER signal represents the dead time due to tdc7200 internal calibration.
Calibration latency deadtime around 2 µs.

2 Firmware and data parsing

The firmware and the data parsing software are available on GitHub link https://github.com/LeonardoLisa/UNO-TDC under GNU General Public License v3 (GPL3). The firmware is hardware specific (Arduino Uno, Atmega328) because it needs direct access to GPIO registers to reduce latencies.

A data logging software is necessary to log the continuous stream of data coming from the UNO-TDC. For this purpose we use PuTTY software but is also possible to use the Arduino IDE serial monitor.

The log file only contains raw data that has to be parsed. The data parsing software takes as input two arguments: the raw log file and the maximum time value for an acceptable measurement. Any measurement longer than the specified time will be ignored. The software saves the parsed data on an output file and prints all the ignored or invalid lines, such as headers, on the console.

The parsing software is available to be compiled for a Windows or a Linux machine.

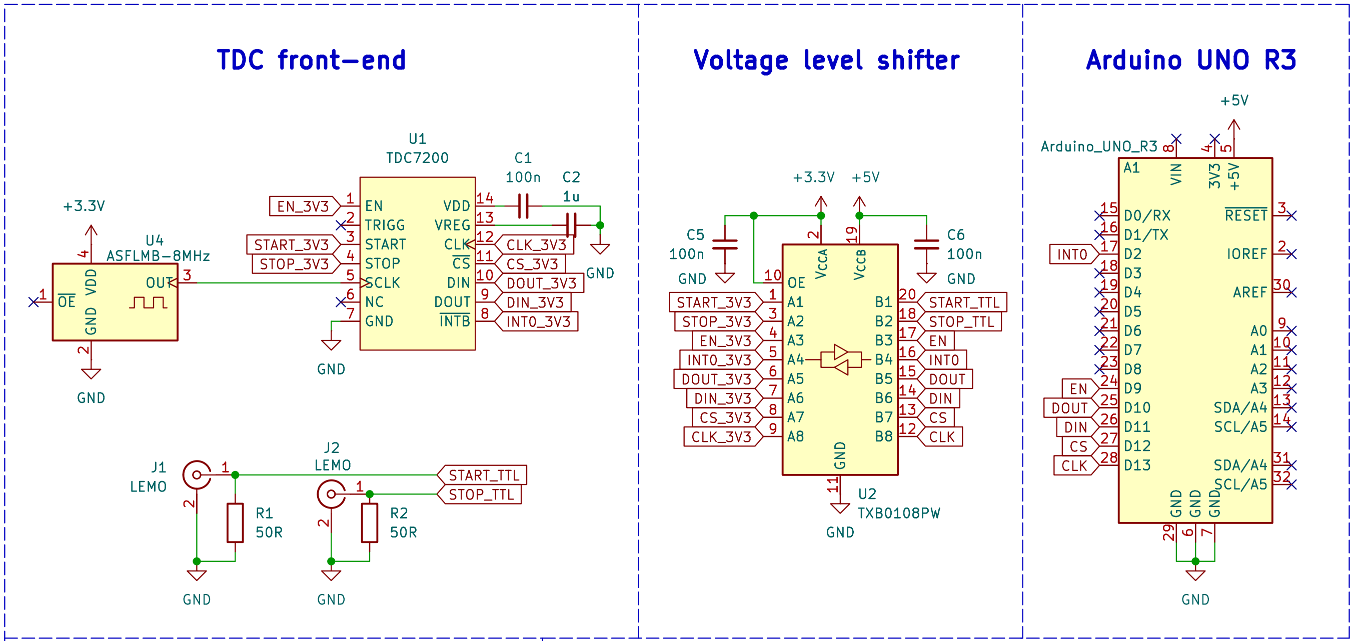
3 UNO-TDC characterization

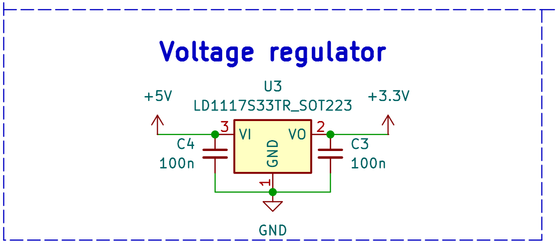
The TDC-UNO is characterized using known START and STOP signals. The signals are generated with a pair of NIM Time Units. The time difference between the two signals is measured with a Lecroy WavePro 7300 3GHz oscilloscope. Due to signal jitter, we assigned 2ns uncertainties to the time difference measured with the oscilloscope. This is our reference value. For each time difference value we took 10 tdc measurements and averaged them. These values are reported in the following table, along with the delta between the time difference and the tdc average. The relative delta is calculated as $100 \cdot \left|\frac{Delta}{Time\ difference}\right|$

UNO-TDC characterization table

Time difference [ns]	σ [ns]	Average [ns]	σA [ns]	Delta [ns]	Delta %
227	2	225.6	0.1	1.4	0.6
501	2	501.3	0.1	-0.3	0.1
1001	2	1008.3	0.2	-7.3	0.7
1799	2	1806.4	0.1	-7.4	0.4
2000	2	2012.9	0.1	-12.9	0.6
2100	2	2113.8	0.2	-13.8	0.7
2198	2	2213.0	0.1	-15.0	0.7
2299	2	2314.9	0.7	-15.9	0.7
2999	2	3021.7	0.2	-22.7	0.8
3502	2	3525.3	2.4	-23.3	0.7

The measurements highlight that UNO-TDC is not as accurate as is it precise and that the systematic error is overwhelmingly larger than the statistical error. However, since systematic error is temperature dependent it may vary during each acquisition and between different acquisition sessions. We decided to consider a 1% error on all tdc measurement ranges.





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