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INTERFACING A WATER FLOW-METER SENSOR TO TDC1000-TDC7200EVM COMBINED WITH A SENSOR INTERFACING PLUG-IN BOARD

Zero Flow Measurement Setup

In this document interfacing of a TDC1000-TDC7200EVM, combined with an external sensor interfacing plug-in board, to a 1MHz Audiowell ultrasonic water flowmeter sensor is described.

The block diagram of the setup is shown in Figure 1. The EVM interfaces to a host PC over a USB interface. A Graphic User Interface (GUI) is used for programming the devices and for displaying the raw data generated by TDC1000 and TDC7200.

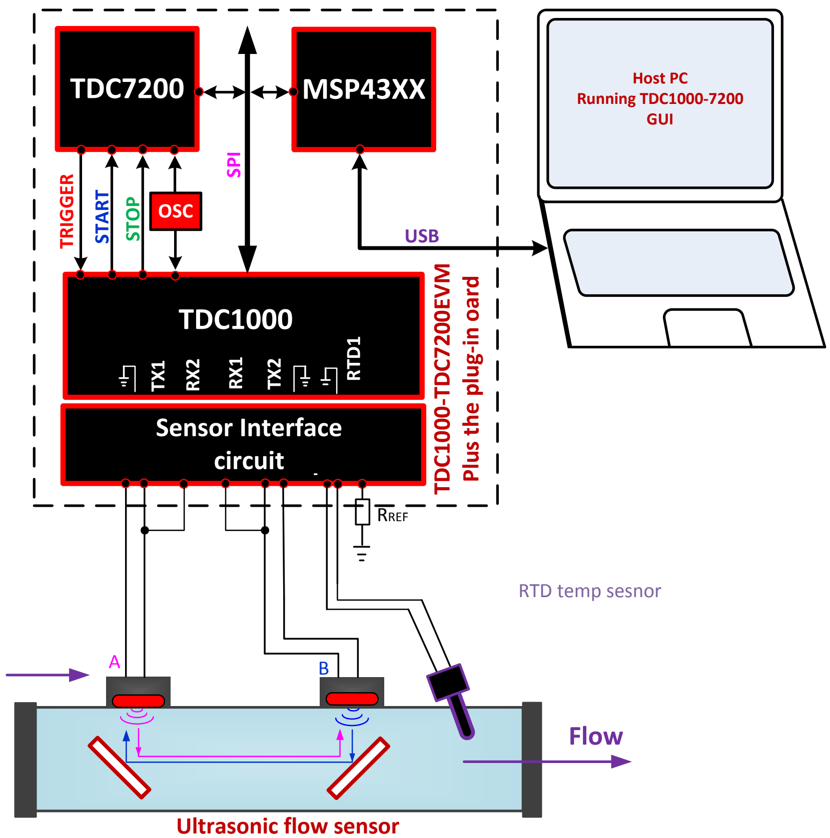

Figure 1: Zero flow measurement block diagram

In Figure 2 the picture of the actual setup and a close up of the TDC1000-TDC7200 and the companion sensor interfacing boards are shown.

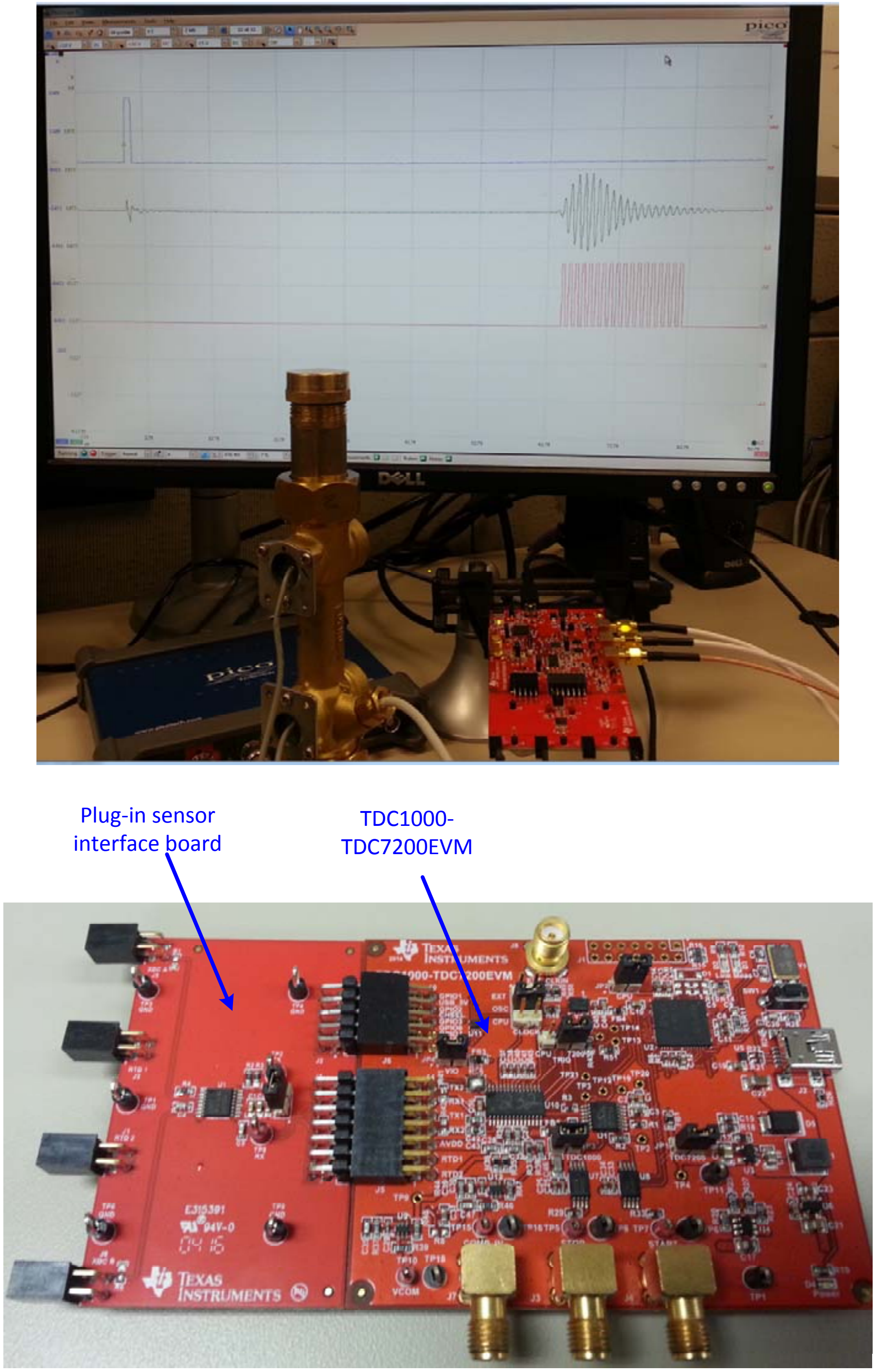

Figure 2: The setup pictures, TDC1000-TDC7200EVM and the plug-in sensor interface board close up

Important note:

The combination of the interface board and the TDC1000-TDC7200EVM is intended for water flow application only (cannot be used for gas flow or level application. The senor interfacing board is only available through special request from the ISC marketing team.

For proper operation of the combination of TDC1000-TDC7200EVM and the sensor interfacing board, as shown in Figure 3, four components namely; R32, R30, C42, and C43 are replace with zero-ohm resistors.

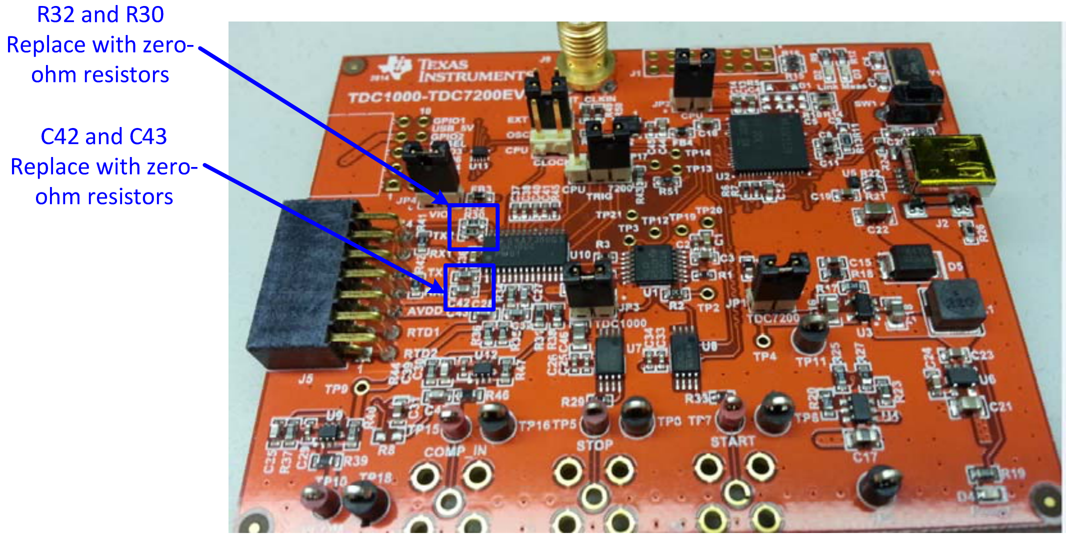

Figure 3: location of the components to be changed on the TDC1000-TDC7200EVM board

In Figure 4, the off-the-shelf 1 MHz ultrasonic sensor used in the setup is shown, the sensor can be obtain from the source provided in the appendix one of this document.

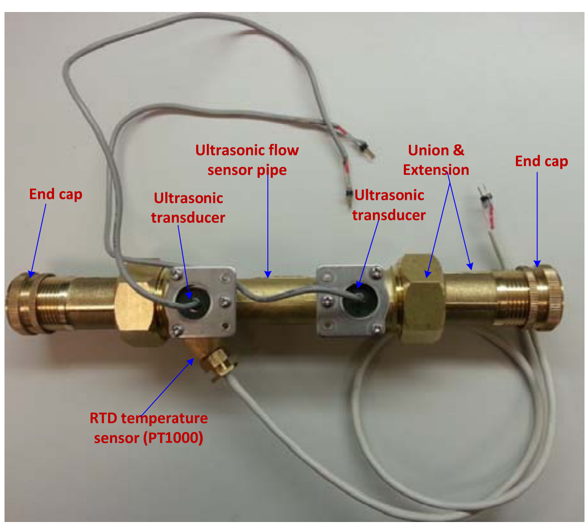

Figure 4. ultrasonic flow-meter sensor pipe

Steps to configure the setup

1. Fill up the sensor with water and secure the end caps. Before securing the end cap, shake out any trapped air bubble in the sensor.
2. Make sure that the R30, R32, C42 and C43 on the EVM are replaced by zero-ohms resistor.
3. Connect the sensor to the sensor interface board and connect the transducer wires and the RTD wires of the sensor to the sensor interfacing boards as or as shown in Figure 5 below. Place the pipe on a flat surface in a standup position as shown if Figure 2. This would move up any bubbles trapped between the two transducers to the top of the pipe and away from the signal path. Bubbles trapped in the signal path causes severe attenuation of signal.
4. You may want to view the signal waveforms (Start, Stop, and Ultrasound received waveform at the input of TDC1000 internal comparators) on a scope to make sure proper operation of the sensor. You can either connect the scope probes to the provided terminals (test points) on the EVM or solder SMA connector on the EVM board and use the cables shown in Figure 5.

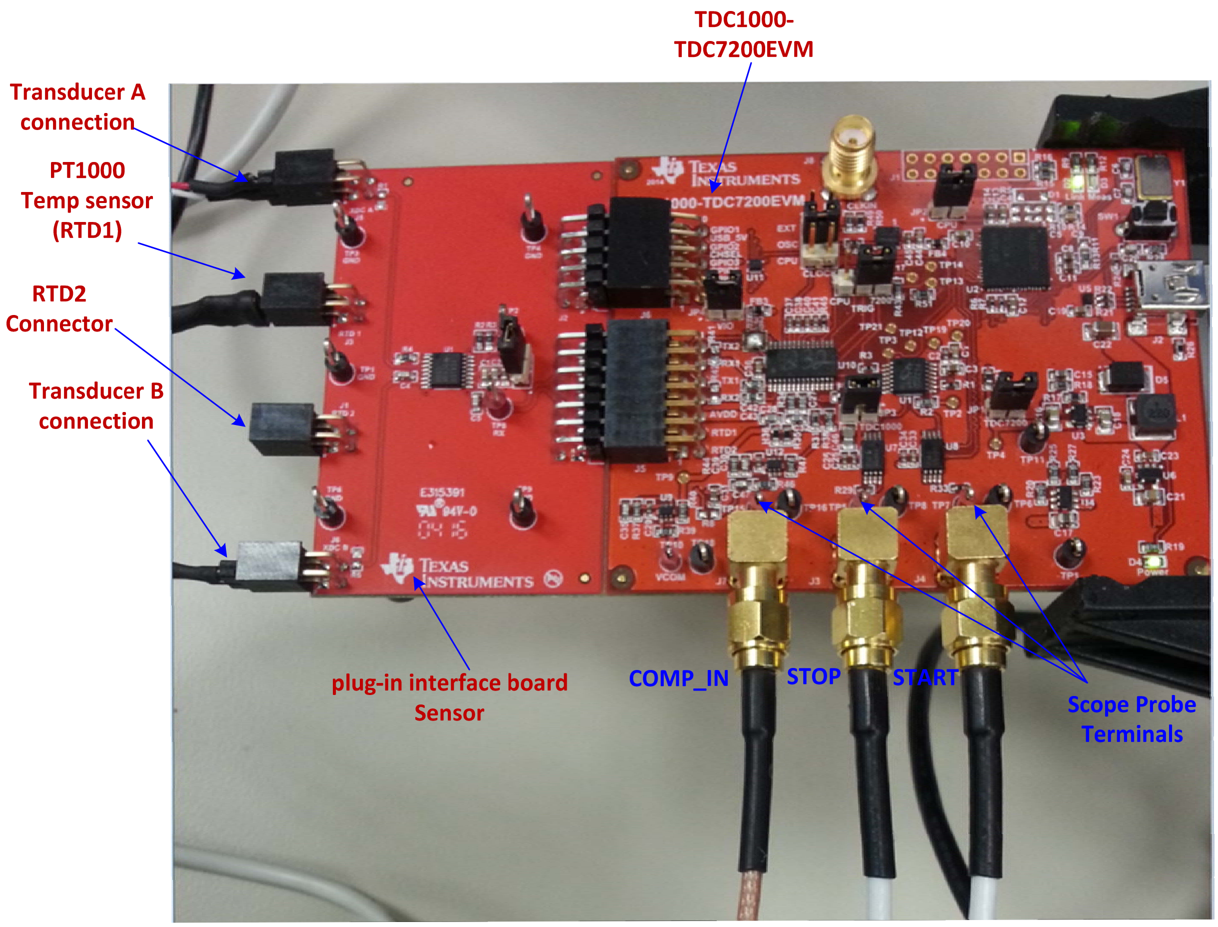

Figure 5: EVM connections to the sensor

5. Install the TDC1000-TDC7200EVM software per the instruction in the user's manual
6. Connect the EVM to the Host PC using the provided USB cable

GUI Configuration

7. Run the GUI; if prompted, upgrade the version of the EVM firmware per the instructions in the TDC1000-TDC7200EVM User's Manual.
8. Set the registers in the "SETUP" and "TDC1000" menu to the values shown in Figure 6, Figure 7, and Figure 8. Flip the "CONTINOUS TRIGGER" switch to the top position (switch will turn to green from red indicating that the system is running).

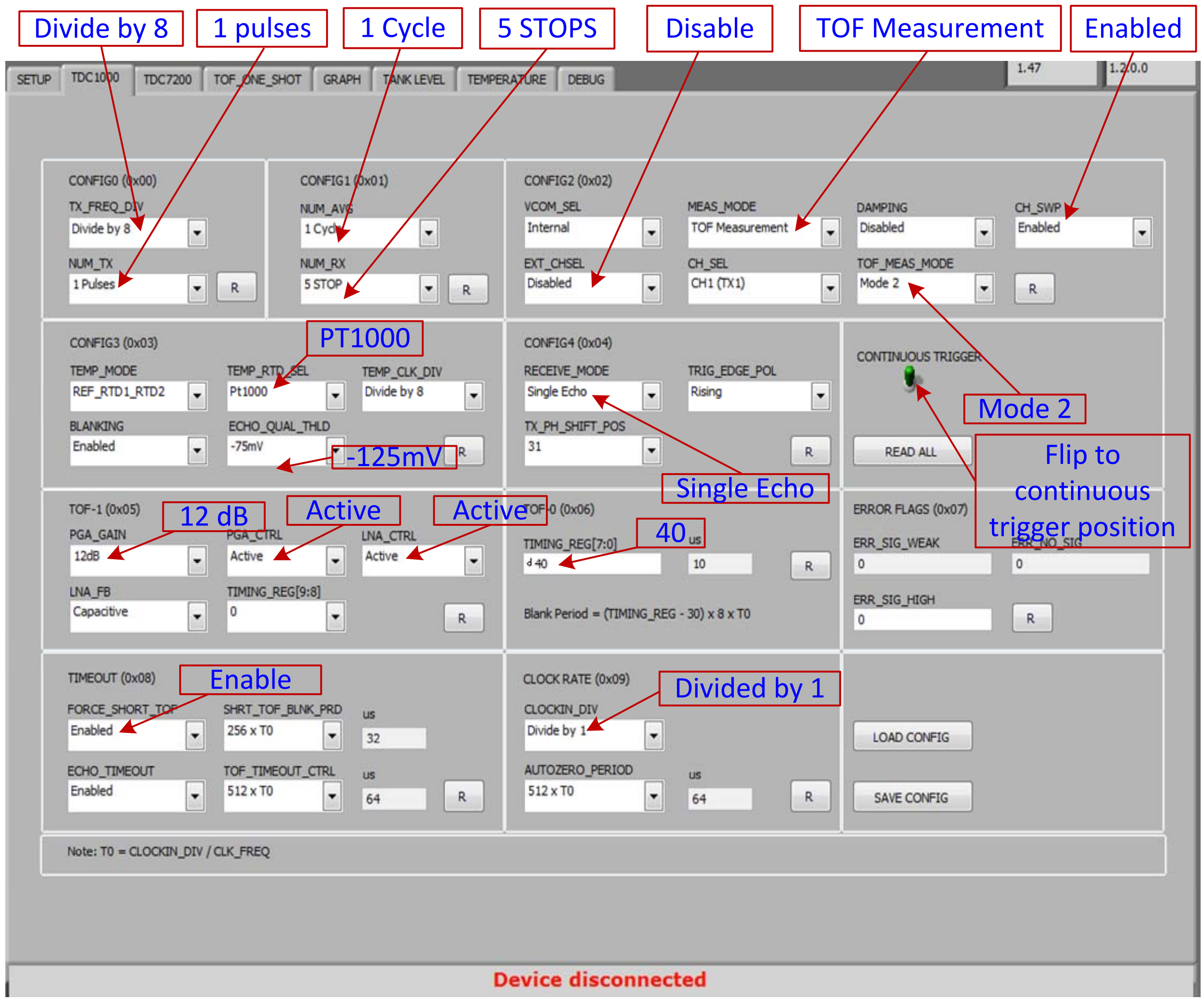

Figure 6: TDC1000 setup menu in the GUI

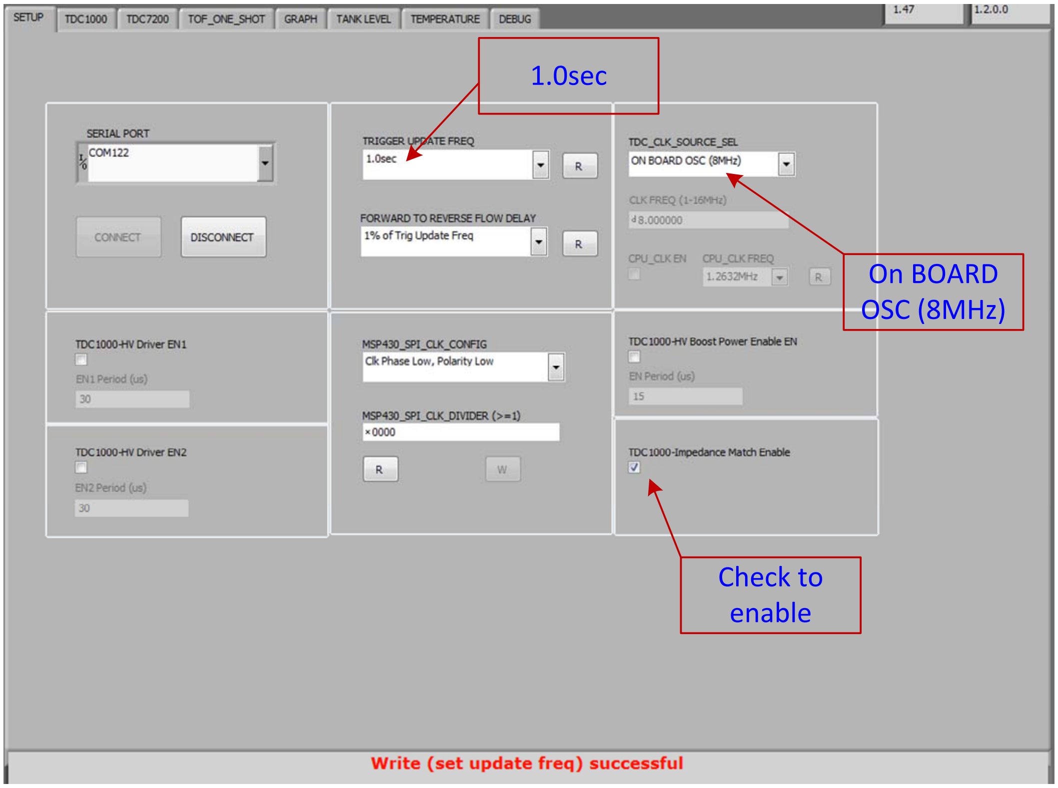

Figure 7: Sampling interval setup

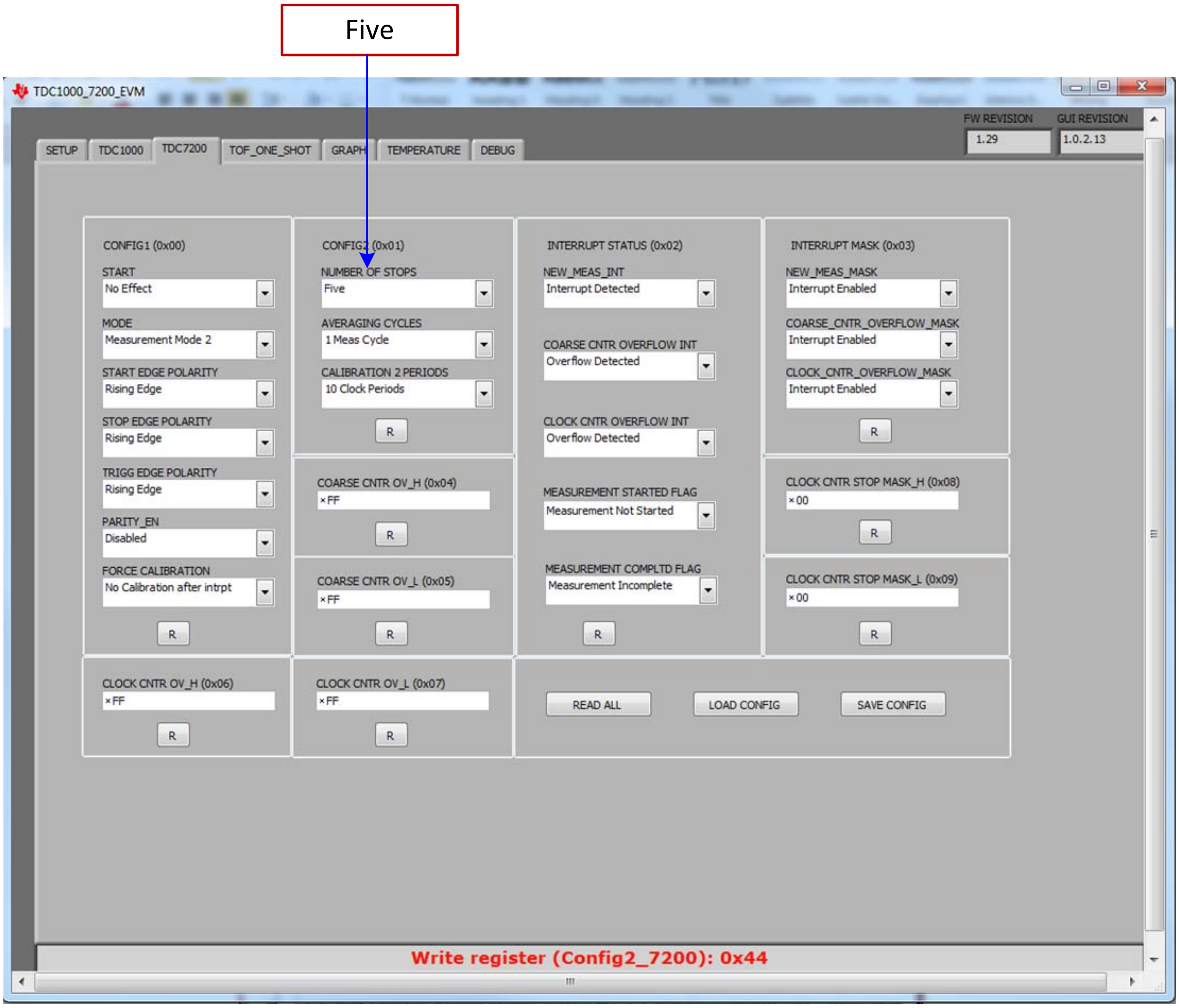

Figure 8: TDC7200 registers setup

Observing the waveform using an oscilloscope

If you are using a scope, use three channels to observe the signal traces as given below:

CHA A :	START, 5V/DIV
CHA B:	STOP, 5V/DIV
CHA C:	COMP_IN, 5V/DIV
Trigger:	Normal, on Ch A
Time base:	20uV/DIV

You should be able to get similar display on you scope screen as shown in Figure 9. The time of flight can be measured reference to STOP pulse one to five. When calculating the delta TOF, if the same STOP pulse is used to measure the TOF for upstream and downstream, the net effect is canceled out and the delta TOF is the same no matter what STOP pulse is used to measure The TOF.

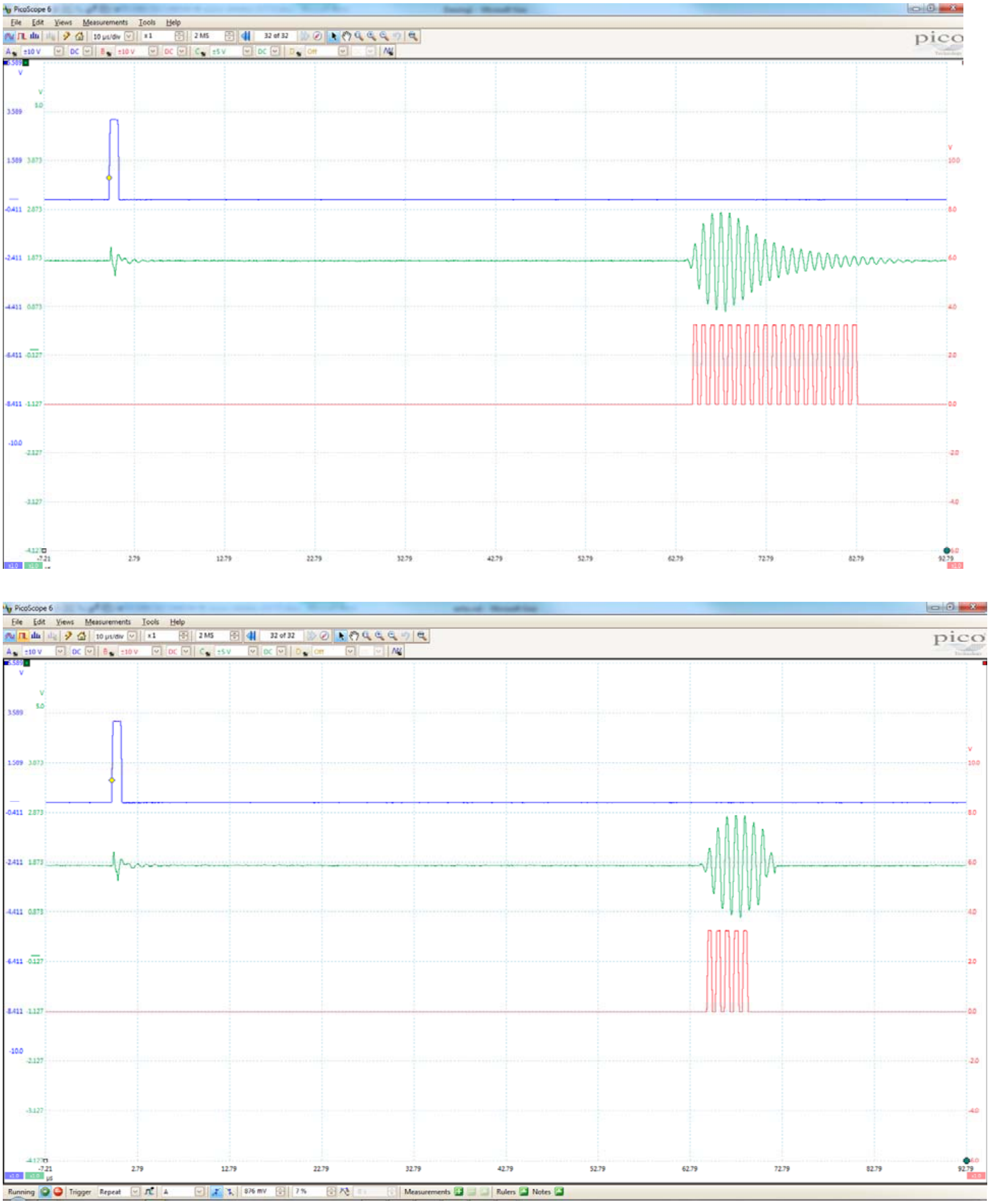

Figure 9: scope trace TOF measurement sequence

Now change the time base of the scope to 200 uV/DIV, you should see the TX/RX sequence for both directions as shown in Figure 10. In mode 2 of TDC1000 operation if CH_SWP is enabled, the state machine upon receiving a trigger pulse will TX/RX in one direction, then switch the direction and upon receiving a second trigger will TX/RX in the other direction.

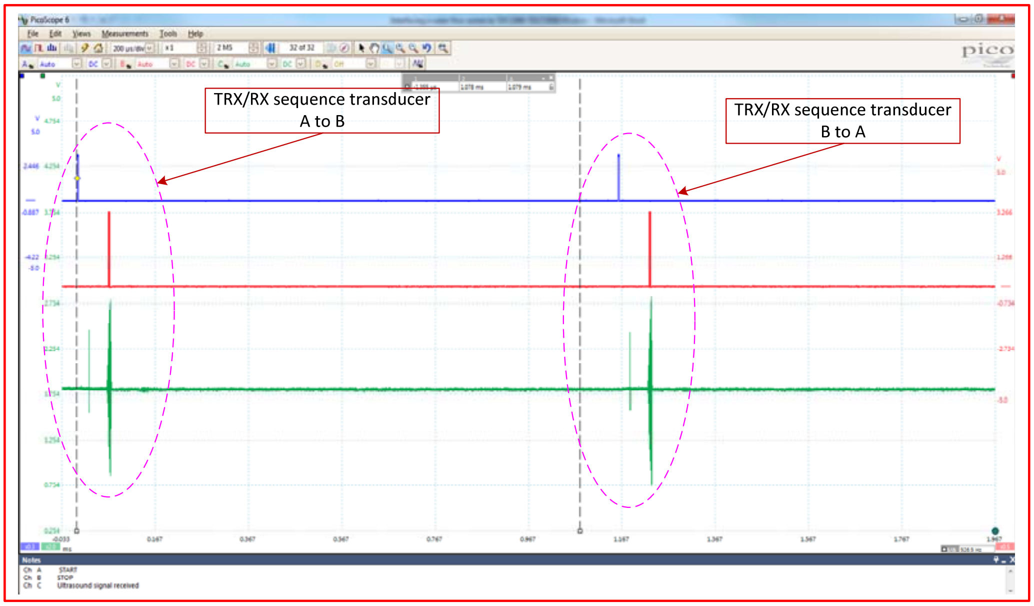

Figure 10: ΔTOF measurement sequence

Displaying the delta TOF in GUI's GRAPH menu

Click on the "GRAPH" tab to display the "GRAPH" menu. In the box below "Flow MODE" on the right bottom corner of the display, check the flow mode option. In this mode the GUI generates a downstream and upstream sequence, calculates the "Delta TOF" and display it at the top right of the screen under "FLOW DELTA AVG (ns)". Under "TDC_SELECT" chose the STOP pulse (STOP1, STOP2, etc) that provides the best accuracy in calculating the TOF. Try different selection and observe the changes in delta TOF and STADEV. As the TOF in the upstream and the downstream directions are measured reference to the same STOP pulse, the net effect is independent of the choice of the STOP pulse.

To start the graph, click on "START Graph" tab, you should see the yellow moving trace of the delta TOF versus time as shown in Figure 10. If the numbers in delta TOF and the STDEV boxes are changing but the graph is not being displayed (black screen) then the graph is out of scale. To force the graph to be displayed in the window, place the cursor on the black background and right-click the mouse. A drop window display will show up giving you the option to select auto scale in the X and Y axis. Once you check mark the auto scale box, the GUI will scale the graph to fit in the display window.

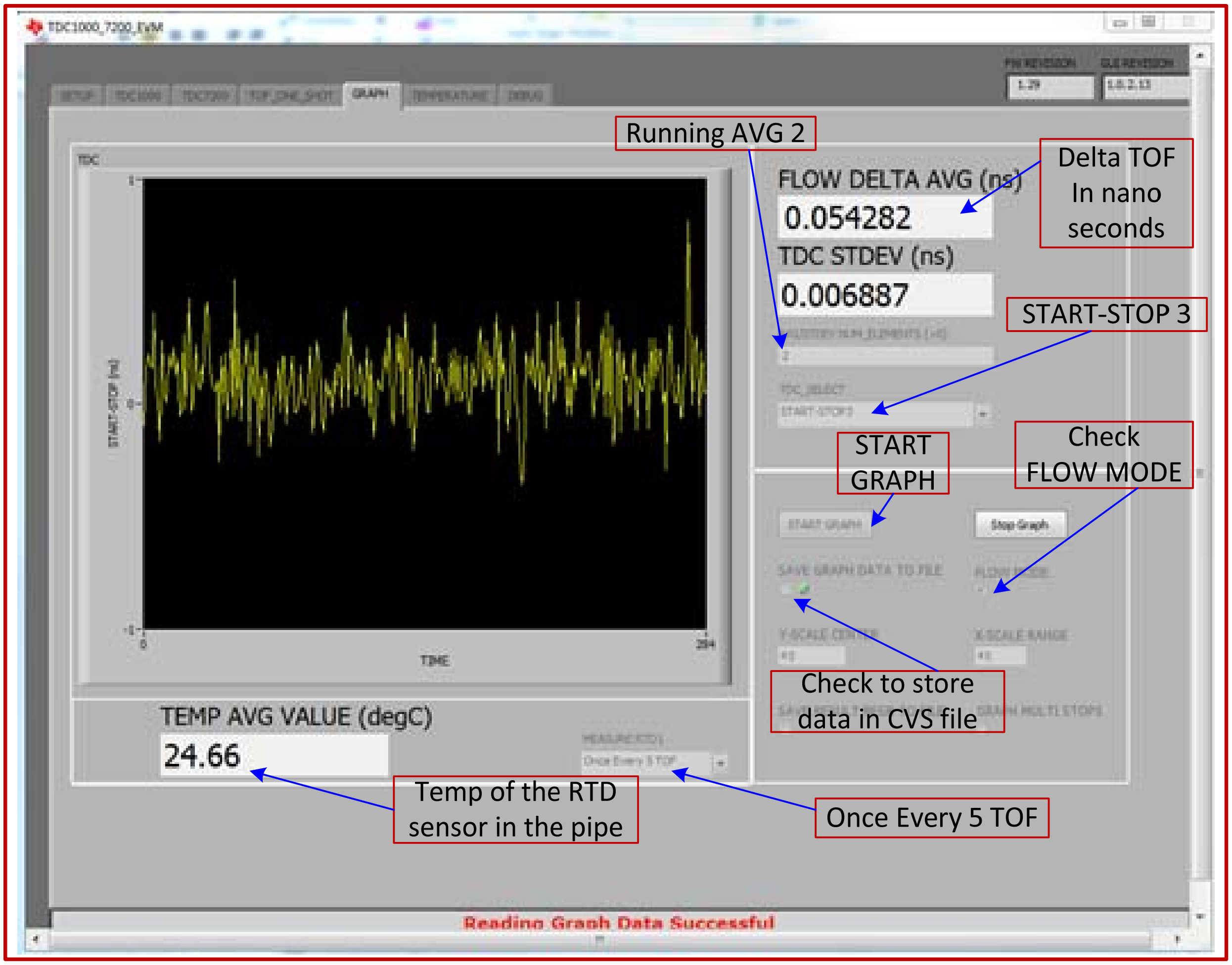

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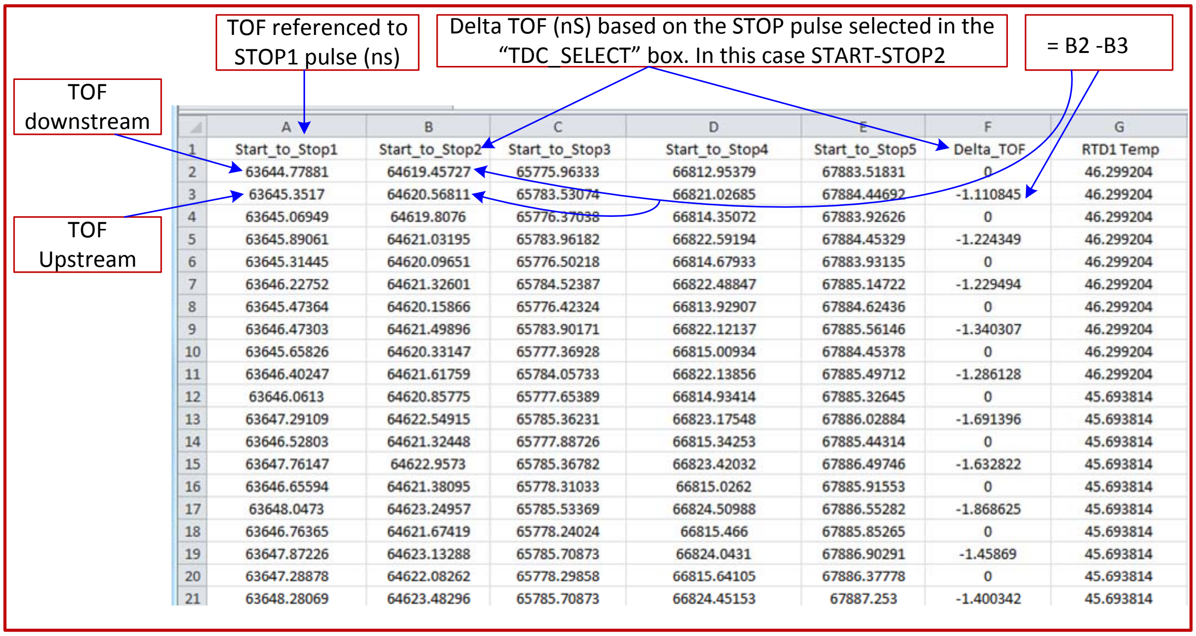
Figure 11: ΔTOF graph display

Saving data in a file

To save data in a file for post processing purpose, check the box “SAVE GRAPH DATA TO FILE” before running the graph by clicking on “START GRAPH” button. You will be asked to name the file and identify a location on your computer to store the file. When you type in the information click the ok tab, you will be prompted to type the number of samples to be saved. If type ok without typing in the number of samples in the displayed box (0 samples by default), the GUI will continuously save unlimited number of data in the file until the “STOP GRAPH” tab is pressed to stop displaying the graph. The content of the file includes information as shown in Figure 13.



	A	B	C	D	E	F	G
1	Start_to_Stop1	Start_to_Stop2	Start_to_Stop3	Start_to_Stop4	Start_to_Stop5	Delta_TOF	RTD1 Temp
2	63644.77881	64619.45727	65775.96333	66812.95379	67883.51831	0	46.299204
3	63645.3517	64620.56811	65783.53074	66821.02685	67884.44692	-1.110845	46.299204
4	63645.06949	64619.8076	65776.37038	66814.35072	67883.92626	0	46.299204
5	63645.89061	64621.03195	65783.96182	66822.59194	67884.45329	-1.224349	46.299204
6	63645.31445	64620.09651	65776.50218	66814.67933	67883.93135	0	46.299204
7	63646.22752	64621.32601	65784.52387	66822.48847	67885.14722	-1.229494	46.299204
8	63645.47364	64620.15866	65776.42324	66813.92907	67884.62436	0	46.299204
9	63646.47303	64621.49896	65783.90171	66822.12137	67885.56146	-1.340307	46.299204
10	63645.65826	64620.33147	65777.36928	66815.00934	67884.45378	0	46.299204
11	63646.40247	64621.61759	65784.05733	66822.13856	67885.49712	-1.286128	46.299204
12	63646.0613	64620.85775	65777.65389	66814.93414	67885.32645	0	45.693814
13	63647.29109	64622.54915	65785.36231	66823.17548	67886.02884	-1.691396	45.693814
14	63646.52803	64621.32448	65777.88726	66815.34253	67885.44314	0	45.693814
15	63647.76147	64622.9573	65785.36782	66823.42032	67886.49746	-1.632822	45.693814
16	63646.65594	64621.38095	65778.31033	66815.0262	67885.91553	0	45.693814
17	63648.0473	64623.24957	65785.53369	66824.50988	67886.55282	-1.868625	45.693814
18	63646.76365	64621.67419	65778.24024	66815.466	67885.85265	0	45.693814
19	63647.87226	64623.13288	65785.70873	66824.0431	67886.90291	-1.45869	45.693814
20	63647.28878	64622.08262	65778.29858	66815.64105	67886.37778	0	45.693814
21	63648.28069	64623.48296	65785.70873	66824.45153	67887.253	-1.400342	45.693814

Figure 12: Sample data stored in a file

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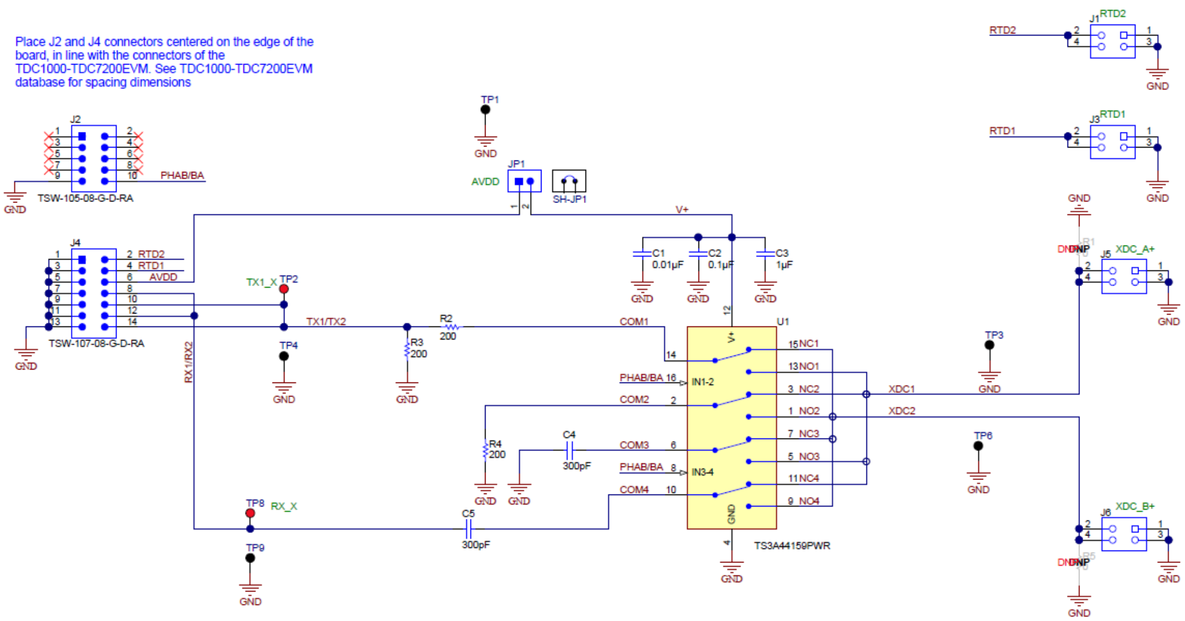
Sensor interfacing board schematic



Appendix 1: Sensor manufacturer

Application	Manufacturer	P/N	FR (kHz)
Heat/water	AudioWell http://www.audiowell.com/en/product-detail.aspx?id=80	Brass Pipe For Heat meter_DN25. Ultrasonic flow sensor_AW5Y0980K04L193Z	1000
Heat/water	AudioWell http://www.audiowell.com/en/product-detail.aspx?id=80	Brass Pipe For Heat meter_DN20. Ultrasonic flow sensor_AW5Y0980K08L151Z	1000

Appendix: 2 Transient-time Ultrasonic Flow-meters Basics

In Figure 13, a typical ultrasonic flow sensor is shown. The sensor consist of a pipe with nominal diameter of "D" and two piezoelectric transducers placed at fixed distance "L" from each other. The transducers are mounted in a protective housing. The housing and the transducers are inserted in the holes in the pipe, exposing the inner cover to the fluid in the pipe. Two reflection mirrors in the pipe direct the ultrasonic signals from one transducer to the other one in the opposite location.

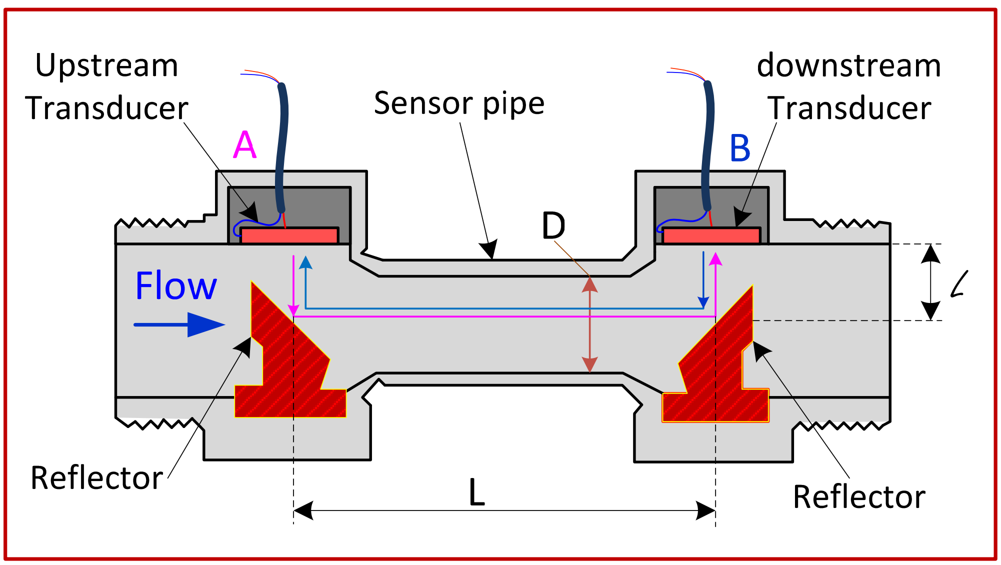


Figure 13: Ultrasonic water flow-meter pipe.

The single path sensor of Figure 13 is used for flow applications where the diameter of the pipe is small. For larger diameter pipes sensors with multiple transducers are used. Other types of ultrasonic flow sensors are available with clamped-on transducers.

Measurement sequence

Referring to Figure 14, the measurement sequence starts by exciting one of the transducer, i.e. "A", by applying a burst of given number of pulses (in Figure 14, three TX pulses) to the transducer. The frequency of excitation signal must be equal to the resonance frequency of the transducer. For water flow applications, transducers with resonant frequency of one to three MHz are used.

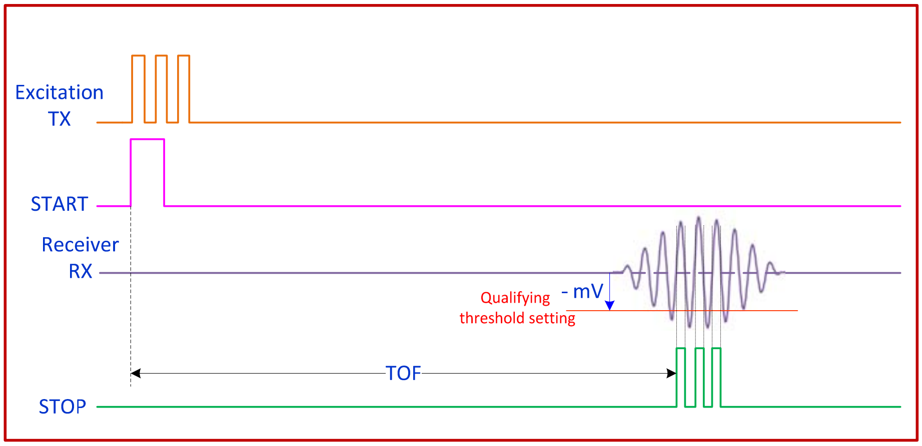


Figure 14: Ultrasonic signal measurement sequence.

The transducer generates ultrasonic pressure pulses that are directed towards the second transducer, in this case B, by means of the reflectors in the pipe. At the same time that the first pulse is being applied to the transducer, a “START” signal is generated to mark the beginning of the “time-of-flight” measurement.

On the receiver side, the electronic circuits in the path condition the received signal and generate a “STOP” pulse to mark the time the ultrasonic pulse is received at the other end. The time taken for the ultrasound wave to travel from one sensor to the other is referred as the “Time-Of-Flight” (TOF). A stop watch is needed to measure the time internal between the “START” and “STOP”, in this case $TOF_{AB.}$

The direction of the transmit/receive sequence is switched and next the TOF_{BA} is measured. The difference between TOF_{AB} and TOF_{BA} is proportional to the velocity of the flow of the medium in the pipe.

Volumetric flow calculations:

The expressions for calculating the TOF between two transducers is given as:

$$\text{TOF} = \frac{Distance\ between\ the\ transduceres}{speed\ of\ sound}$$

Referring to Figure 1 , the expressions for TOF for downstream (TOF_{AB}) and upstream (TOF_{BA}) are:

$$TOF_{AB} = \frac{1}{C} \angle + \frac{L}{C+V} + \frac{1}{C} \angle \qquad (1)$$

$$TOF_{BA} = \frac{1}{C} \angle + \frac{L}{C-V} + \frac{1}{C} \angle \qquad (2)$$

$$\Delta T = TOF_{BA} - TOF_{AB} \qquad (3)$$

Where:

$\measuredangle = {}^{D}/_{2}$; *D is the inner diameter of the pipe*

C = *Speed of sound in the medium*

V = *Average velocity of the medium (fluid/gas) in the pipe*

Rearranging the terms and solving for V:

$$\Delta TOF = \left(\frac{D}{C} + \frac{L}{C-V}\right) - \left(\frac{D}{C} + \frac{L}{C+V}\right)$$

$$= \frac{L2}{C-V} - \frac{L2}{C+V}$$

$$= \frac{(c+V)L-(C-V)L}{C^2-V^2}$$

$$\Delta T\,(C^2 - V^2) = 2 * L * V$$

Since $C \gg V$

$$(C^2 - V^2) \sim C^2$$

And

$$\Delta T * C^2 = 2 * L * V$$

$$V = \frac{\Delta T * C^2}{2L} \qquad (4)$$

Calculation of Volumetric Flow rate, Q

The relationship for calculate the volumetric flow rate is:

$$Q = K * V * A$$

Where:

K = Pipe calibration factor depending on the sensor

V = Average velocity though of the fluid in the pipe.

A = The cross-sectional area of the meter pipe.

TDC 1000 uses a common approach known as “zero-crossing” method to generate the “START” and “STOP”. At low flow rates, the difference between TOF_{AB} and TOF_{BA} is very small, for this reason a highly accurate timer such as TDC7200 with picoseconds resolution is required.