Application Report

Short and Mid-Range Ultrasonic Application Optimization and Usage Guide: TUSS4470 and TDC1000

Gabriel Lake

ABSTRACT

The TDC10xx and TUSS4470 ultrasonic AFE devices both support water and air-coupled Time of Flight (ToF) applications due to their supported transducer frequency range. This application report provides detailed usage instructions and comparison of the TDC1000 and TUSS4470 in a short and mid-range air-coupled level sensing and a short range water-coupled level sensing evaluation. Data is presented over a series of tests to compare the performance and tradeoffs of each device, and includes discussion of common usage errors and design challenges such as transducer ringing decay and range limitations. The information and data presented for the TDC1000 also applies to the TDC1011.

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1 Review of Ultrasonic Sensing Range Performance Factors

The effects on ultrasonic ToF range related to the test data presented in this document are categorized into three types of system properties that are either fixed or varied by the designer: physical parameters, transducer characteristics, and AFE device settings.

1.1 Physical Parameters

The ultrasonic wave transmission medium, target composition, and target radar cross-section fundamentally impact the attainable range using a given transducer. For example, air-coupled ultrasonic transmissions are practically limited to below 500 kHz due to the wave dissipation through air. Generally, transmission range is inversely proportional to transducer frequency. The material composition and acoustic impedance mismatch of the target impacts the attenuation of the wave as it is reflected off of the surface.

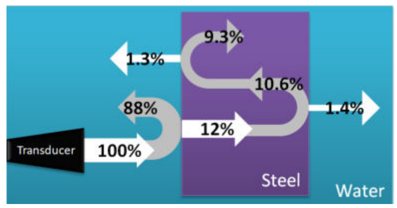


Figure 1-1. Reflection Coefficients for Water and Steel Boundaries

Likewise, scattering or wave misdirection, due to the radar cross section of the target, can have a major impact on the return ultrasonic echo SPL.

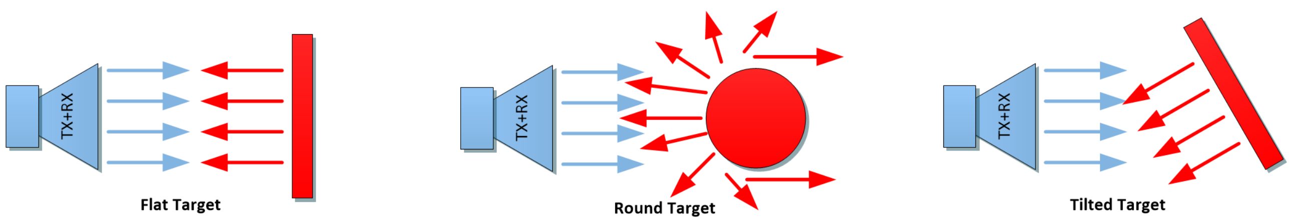


Figure 1-2. Target Geometry Impact

1.2 Transducer Characteristics

A transducer's diameter, mechanical packaging and quality factor also have a measurable impact on transmission range. In one common definition, the quality factor of a mechanical-electrical oscillator is proportional to the reciprocal of its resonant half power bandwidth. The Q-factor can be described similarly by the ratio of energy stored to energy dissipated per cycle of the oscillation. For example, a perfect transducer would have an infinitely narrow bandwidth and an infinite Q-factor, and the BVD model of this theoretical transducer is a lossless LC oscillator. Thus, a transducer with a higher Q-factor will have a longer oscillation decay than a transducer with a lower Q-factor

The damping of a commercial transducer is related to the resistance of the BVD model (RLC circuit). The BVD model's damping resistance corresponds to the overall damping characteristic of the transducer, which is a function of the transducer packaging, such as the enclosure and backing material surrounding the piezo element, as well as trace electrical resistance.

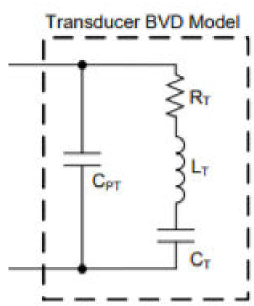


Figure 1-3. Transducer BVD Model

The ring down period of a transducer is the length of time that the transmit signal takes to decay, also known as the blind-zone in reference to a plotted signal. The reflected ultrasonic pulse cannot be received within the ring down period. One method for reducing the ring down time is to increase the resistance of the RLC model of the transducer by mechanical or electrical means (utilizing mechanical damping or a parallel damping resistor).

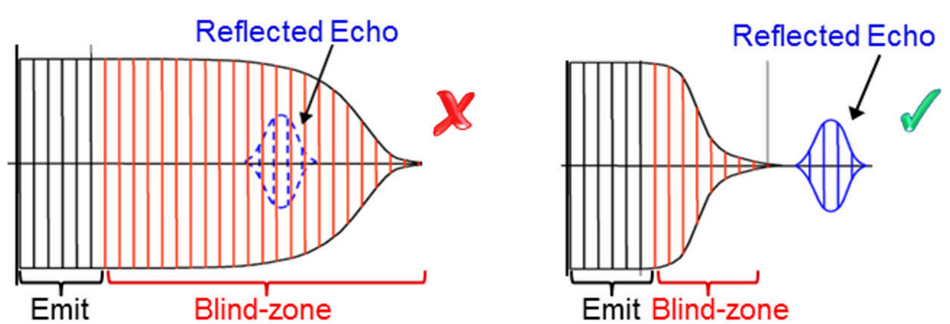


Figure 1-4. Monostatic Ring Decay

1.3 AFE Device Configuration

If unfamiliar with ultrasonic AFEs, this TI Precision Labs video series provides a good introduction. Transducer drive settings such as driver type (DC switching or transformer topology), number of transmit excitation pulses, current limit, receiver gain, and transmit voltage level impact the minimum and maximum ToF range achievable. For further background on the implications of these settings and system optimizations, see Section 8.

2 Methods Overview

2.1 Introduction

The purpose of this document is to provide a comparison between the TDC1000 and TUSS4470, which have overlapping frequency range support, but differing methods of configuration, operation and ToF data collection. The remainder of this report will cover the following:

1. Hardware and firmware configuration of the TUSS4470EVM and TDC1000-C2000EVM for:
    a. Short and mid-range air-coupled ToF measurements with a 220 kHz transducer
    b. Short range water-coupled ToF measurements with a 1 MHz transducer
2. TUSS4470EVM and TDC1000-C2000EVM short range air-coupled water level sensing test results
3. TUSS4470EVM and TDC1000-C2000EVM mid-range air-coupled water level sensing test results
    a. Including TUSS4470EVM 5V and 35V drive voltage operation
4. TUSS4470EVM and TDC1000-C2000EVM short range water-coupled water level sensing test results
5. TUSS4470 and TDC1000 resistive damping comparison

2.2 Hardware Configuration

2.2.1 Transducers

Air-coupled testing was performed with the 220kHz Massasonic Model E-188/220 transducer.

Water-coupled testing was performed with the 1MHz Steminc SMD15T21R111WL piezo disc transducer.

2.2.2 Experimental Setup: Air-Coupled Level Sensing

For the short range test, the EVMs and transducer were mounted on a test fixture placed over the opening of an 8 gallon tank containing water, and the same fixture was mounted over a utility tub containing water, for the mid-range test. The transducer was mounted flush with a plexiglass plate, held in place by friction and a dot of viscous CA (super glue).

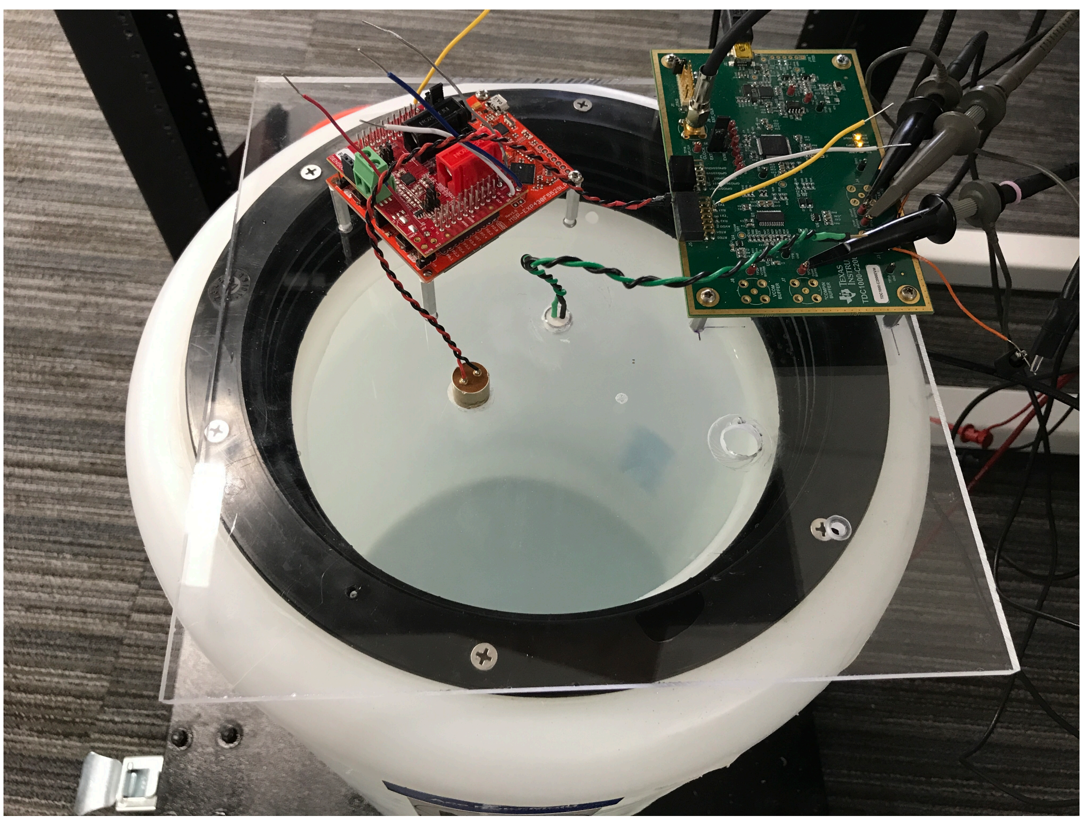


Figure 2-1. Short Range Air-Coupled Level Sensing Test Environment

Figure 2-2. Mid-Range Air-Coupled Level Sensing Test Environment

2.2.3 Experimental Setup: Water-Coupled Level Sensing

The piezo disc transducer was mounted to the bottom of the small plexiglass tank shown in Figure 2-3, following the procedure described in *How to Select and Mount Transducers in Ultrasonic Sensing for Level Sensing and Fluid ID*.

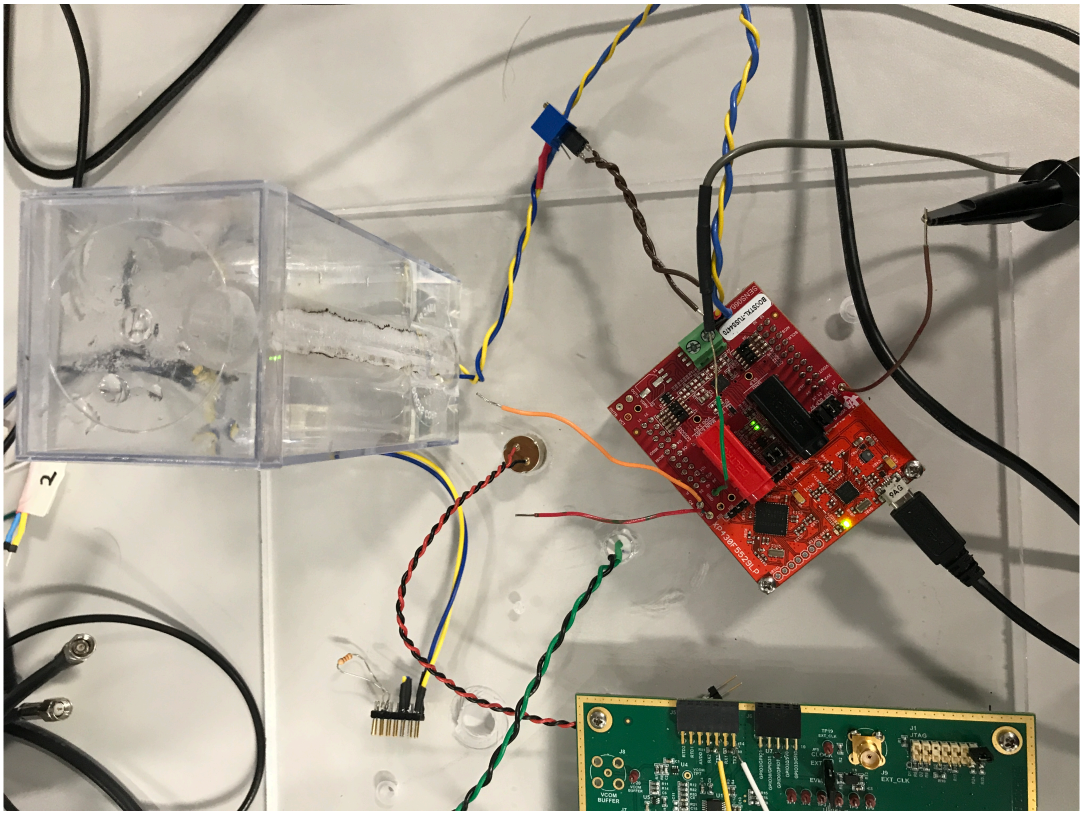


Figure 2-3. Short-Range Water-Coupled Level Sensing Test Environment

2.2.4 TUSS4470 EVM Hardware Configuration

The following modifications were made from the default configuration:

- Setting the CINN and CFLT capacitor banks to support the 220kHz and 1MHz transducers, respectively. For more information, see Appendix A or the *Recommended Component Values for Typical Applications* table in the *Typical Applications* section of the *TUSS4470 Direct Drive Ultrasonic Sensor IC With Logarithmic Amplifier Data Sheet*. Capacitors are selected with jumpers on J1 and J4.
- The power mode jumpers located on J6 and J8 were set depending on the drive voltage required for the test. For more information, see the *Power Mode Jumper Position* table in *TUSS44x0 EVM for Ultrasonic Sensors User's Guide*.
- J3 was populated with a two pin female header for connecting the transducers in the half-bridge driver configuration.

2.2.5 TDC1000-C2000EVM Hardware Configuration

Channel 1 (TX1/RX2) was configured for the 220 kHz transducer:

- Band-Pass Filter: 150 kHz - 1.2 MHz pass band. For implementation instructions see the *Receiver Filters* section in the *TDC1000 Ultrasonic Sensing Analog Front End (AFE) for Level Sensing, Flow Sensing, Concentration Sensing, and Proximity Sensing Applications Data Sheet*.
- LNA Feedback: replace the default 300pF capacitor on C4 with a 900Ω resistor. This is necessary for transducers below 500 kHz.
- Jumper JP1 pins 2-3 shorted to connect an external clock source.

Channel 2 (TX2/RX1) was configured for the 1 MHz transducer:

- Default out-of-box band-pass and LNA feedback values were used.
- The EVM 8 MHz MEMs oscillator served as the TDC1000 input clock source, JP1 pins 1-2 shorted.

2.3 Firmware Configuration

2.3.1 TUSS4470 Power Configuration

The TUSS4470 registers are easily configured in the 'Device Monitor' or 'Memory Map' tab of the TUSS Generation III EVM GUI. Some of the key register settings for device configuration are listed and discussed below.

The TUSS4470 EVM can be configured for a 5 V - 36 V VDRV voltage based on Table 2-1. The device configuration enumerated in each column will enable the respective voltage range for VDRV. **Where register names are not explicitly listed, the value corresponds to the value seen in the TUSS Generation III EVM GUI.**

Table 2-1. TUSS4470EVM Voltage Configuration Guide

HW/FW Setting	5 V	5 V- 20 V	5 V- 36 V
J6 pin 5-6 jumper	short	open	open
VDRV External supply	NC (1)	NC	5 V- 36 V
VPWR External Supply	NC	VDRV_VOLTAGE_LEVEL+5V+0.3V	VDRV+0.3V
VDRV_HI_Z	Not HiZ	Not HiZ	HiZ
VDRV_VOLTAGE_LEVEL + 5V	5 V	5 V- 20 V	X (2)

1. Not Connected
2. Don't Care

2.3.2 TUSS4470 220 kHz Configuration

Table 2-2 shows example starting values for short to mid range evaluation of the TUSS4470 with a 220 kHz transducer and the TUSS Gen III EVM GUI.

Table 2-2. TUSS4470 220 kHz Suggested Evaluation FW Setup

TX Setting	Short Range Value	Mid-Range Value	RX Setting	Value	Output Setting	Short Range Value	Mid-Range Value
BURST_PULSE	4	10	**BPF_HPF_FREQ**	218.26 kHz	ECHO_INT_COMP_EN	Disabled	Disabled
HALF_BRG_MODE	Enabled	Disabled	**LOGAMP_DIS_LAST_GM**	Enabled	Record (GUI record time)	12 ms	24 ms
Frequency	220 kHz		**LOGAMP_DIS_FIRST_GM**	Enabled			

Evaluation Notes:

From this starting point, tuning will almost always be required to achieve the desired VOUT output across a given ToF range. When ring down is a concern, four burst pulses was experimentally determined to serve a wide ToF range with a relatively short blind zone. When the ring down time is not important, 10 burst pulses is a good starting point. Also note that while it is recommended to start tuning with the logarithmic amplifier stages enabled for air-coupled measurements, disabling the first and last stage with LOGAMP_DIS_FIRST_GM and LOGAMP_DIS_LAST_GM can reduce errors in threshold detection since the noise floor is lower and can be more stable. However, the dynamic range will be reduced as well. In this testing, a smooth noise floor was favored over dynamic range for very short ToF or high VDRV measurements.

ECHO_INT_COMP_EN is disabled above because it is recommended that the expected VOUT is verified before enabling the echo interrupt. If the echo interrupt is desired, a threshold may be set to the necessary level with the ECHO_INT_THR_SEL bits once the device settings are adjusted for the desired VOUT.

2.3.3 TDC1000 220kHz Configuration

Table 2-3. TUSS4470 Suggested 1MHz Evaluation FW Setup

TX Setting	Short Range Value	Mid-Range Value	RX Setting	Value	Output Setting	Short Range Value	Mid-Range Value
BURST_PULSE	1-3	10	**BPF_HPF_FREQ**	400p	**ECHO_INT_ COMP_EN**	Disabled	Disabled
HALF_BRG_ MODE	Enabled	Disabled	**LOGAMP_DIS_ LAST_GM**	Disabled	**Record (GUI record time)**	12 ms	12 ms
Frequency	1 MHz		**LOGAMP_DIS_ FIRST_GM**	Disabled			
			BPF_BYPASS	Enabled			

Evaluation Notes:

The band pass filter is configurable for use up to 500 kHz. For 1 MHz transducer operation, BPF_BYPASS should be set to one, converting the BPF to a HPF with cut-off frequency BPF_HPF_FREQ set to 400 kHz. In short range water-coupled applications, the dynamic range of the received echo should be sufficient without the log amplifier enabled. Probing VOUT with an oscilloscope will show more accurate results than the GUI VOUT plot due to the higher sampling rate of the scope. The ADC used to sample VOUT by the host MCU samples at 1 MSPS.

2.3.4 TDC1000 220kHz Configuration

Because the TDC1000's architecture is optimized for higher frequency liquid-coupled applications, utilizing the TDC1000 for air-coupled evaluation requires more fine tuning and patience than the TUSS4470. Table 2-4 provides recommended values as a starting point, allowing a ToF in the range 128 × T0 up to 128 × T0 + 1024 × T0. **Values are given in the GUI format, see the TDC1000-C2000EVM GUI and the TDC1000 data sheet programming section for corresponding register values.** For a short ToF measurement time line graphic and T0, T1 definitions, see Appendix B.

Table 2-4. TDC1000 air-coupeld suggested evaluation FW setup

GUI Setting	GUI Value	Comments
TOF_MEAS_MODE	0	Measurement mode 0 for mono-static ToF measurements
Recieve Mode	Single or Multi- Echo	
CLOCKIN_DIV	Div by 1	Set T0 with CLOCKIN_DIV
FORCE_SHORT_TOF	Enabled	The short ToF mode allows the common-mode voltage settling time (128 × T0) to occur before the TX burst, so that the COMPIN signal will be less noisy and the listen period may be maximized.
TOF_TIMEOUT_CTRL	1024 × T0	This allows a maximum echo listen period of approximately 4.6 ms.
NUM_TX	10 - 15 pulses	This is a good starting point for producing a strong return echo.
NUM_RX	No RX Event Count	This allows STOP signals to be generated for the duration of TOF_TIMEOUT_CTRL, avoiding ending the measurement due to an erroneously generated STOP.
PGA_GAIN	21 dB	The maximum gain is recommended for air-coupled evaluation.
ECHO_QUAL_THLD	-35 mV	The most sensitive echo threshold setting may be necessary to trigger a STOP.
LNA_FB	Resistive	Required for transducers in this frequency range.
AUTOZERO_PERIOD	64 × To	In short ToF mode, this period occurs before the TX burst and can be adjusted if needed.
SHRT_TOF_BLNK_PRD	128 × T0	This should allow plenty of time for noise coupled from the TX line to settle and have a clean COMPIN for viewing the return echo.

Evaluation Notes:

Signals of interest: START, STOP, COMPIN, TX.

For short range measurements, the blanking period may need to be shortened so the return echo can trigger a STOP. Depending on the transducer frequency, the transducer ringing decay could couple noise onto the COMPIN signal path causing a false STOP to be triggered at the beginning of the listen period. If this occurs, the blanking period can be set to mask this noise, or other means of ignoring a false STOP may be required at the designer's discretion. This is a good reason to set an unlimited NUM_RX event count for initial evaluation.

2.3.5 TDC1000 1 MHz

The default settings listed in Table 2-5 are a good starting point for water-coupled ToF applications. It is recommended to perform a simple tank test with these settings for first time evaluation of the TDC1000. For comments on measurement timing below, T0 = 125 ns (1/8 MHz).

Table 2-5. TDC1000 Water-Coupled Suggested Evaluation FW Setup

GUI Setting	GUI Value	Comments
TOF_MEAS_MODE	0	Measurement mode 0 for mono-static ToF measurements
Recieve Mode	Single or Multi-Echo	
CLOCKIN_DIV	Div by 1	Set T0 with CLOCKIN_DIV
FORCE_SHORT_TOF	Disabled	Standard ToF measurement mode
TOF_TIMEOUT_CTRL	1024 × T0 (128 µs)	This allows a maximum echo listen period.
NUM_TX	4- 15 pulses	This is a good starting point for producing a strong return echo.
NUM_RX	1 STOP	With a higher threshold allowed, and stronger return pulse expected, only one STOP is necessary.
PGA_GAIN	6dB	0 - 6dB should be sufficient
ECHO_QUAL_THLD	-220mV	Default value
LNA_FB	Capacitive	Required for transducers in this frequency range.
AUTOZERO_PERIOD	128× To (16 µs)	In the standard ToF measurement mode, this period occurs just before the listen period.
TIMING_REG	30	For more information, see [7].
FORCE_SHORT_TOF	Disabled	Standard measurement mode

Evaluation Notes:

Details on procedure can be found in the TDC1000-C2000EVM *TDC1000-C2000EVM User's Guide* and in *How to Select and Mount Transducers in Ultrasonic Sensing for Level Sensing and Fluid ID*.

A suitable tank size for this evaluation can be determined based on the timeline diagram (Appendix B) for the standard ToF measurement. Assuming 10 TX pulses and the settings in Table 2-5, the measurement range may be determined from this timing table - (T0 = 125 ns, T1 = 1 µs).

Table 2-6. TDC1000 Air-Coupled Measurement Timeline Example

TRANSMIT	WAIT	COMMON-MODE	AUTOZERO	ECHO LISTEN
NUM_TX × T1	(TIMING_REG-30) × 8 × T0	128 × T0	128 × T0	1024 × T0
10 µs	0 µs	16 µs	16 µs	128 µs

Minimum ToF: (10 + 0 + 16 + 16) = 42 µs

Maximum ToF: 42 µs + 128 µs = 170 µs

Assuming c = 1480m/s in water, the water level in the evaluation tank should be between about 3.2cm and 12.5cm. The WAIT time period should be adjusted to shift the echo-listen period as needed.

3 Short Range Air-Coupled Test Results

3.1 TUSS4470

For each measurement, the VOUT waveform was captured from the TUSS Generation III GUI data plotter tool. Four plots show the peaks corresponding to the TUSS4470 conditioned output of the received echo waveform for decreasing ranges (increasing water level). The distances shown in the legend were computed in post processing.

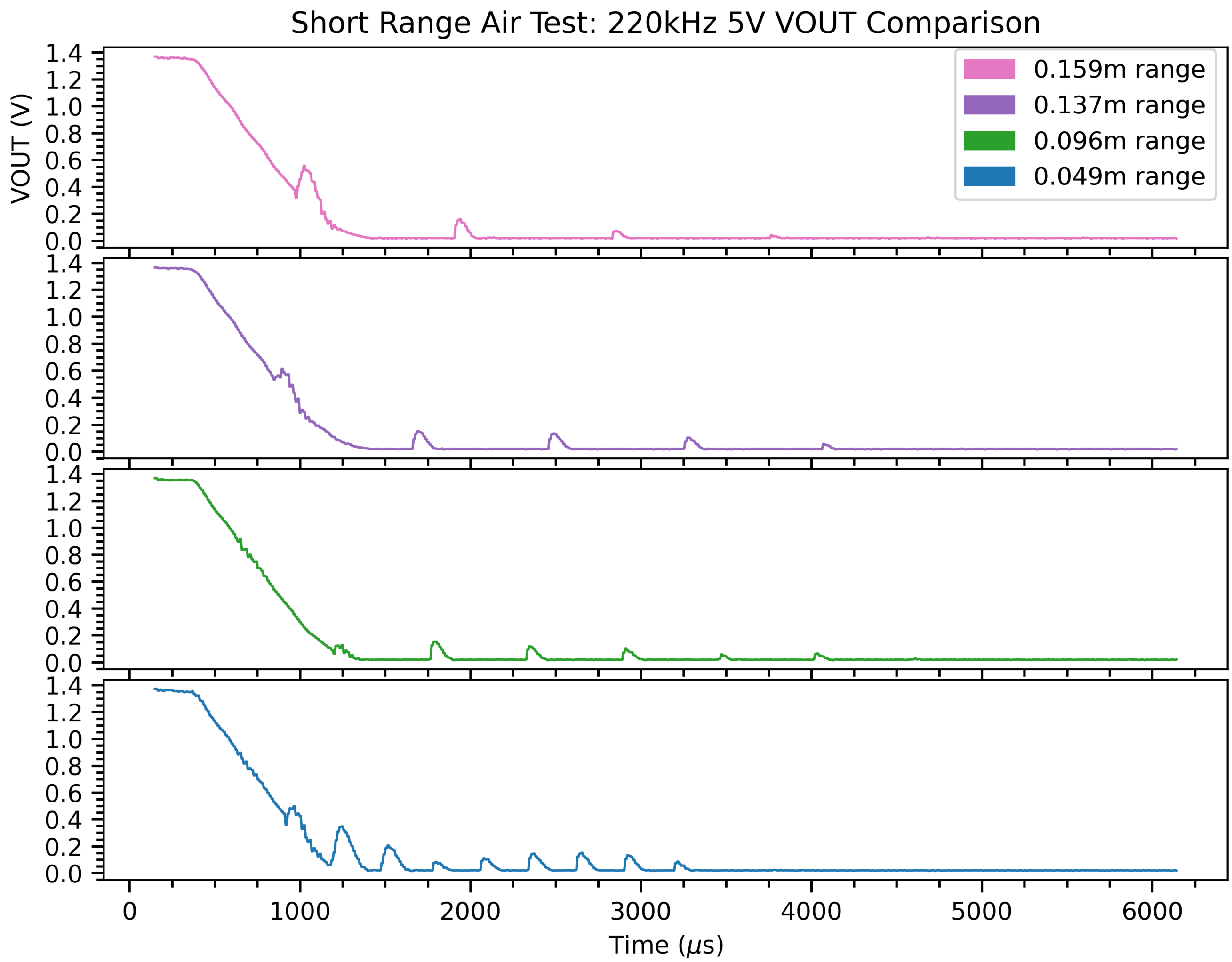


Figure 3-1. Short Range Air-Coupled Results: TUSS4470

As the range decreases, multiples of the return echo are visible due to decreased attenuation of the ultrasonic pulse between the transducer and target, which allows the wave to reflect back and forth several times before dissipating entirely. The top waveform (0.159m) shows the first echo at the 1 ms mark followed by the second and third reflection. At a certain range, the first echo will fall into the blind zone, where it will be impossible to detect it from ADC samples. In short range applications with a very reflective target, subsequent reflections can be used to measure the ToF. In post processing on this data, ToF was computed as an average of the time between each pair of adjacent return echos. A software threshold was used to detect the beginning of each pulse on VOUT. In applications that require very short range measurements, this method can be down to a range where return echos are too close to distinguish. Note that 4.9cm recorded above is not the minimum range for this device setup. This ToF measurement principle can be applied with a real-time processing algorithm by keeping track of the number of samples between threshold crosses. The echo interrupt available on the OUT4 pin is a less costly option for measuring ToF, however, the echo pulse must reach the minimum interrupt threshold of 0.4V.

3.2 TDC1000

Five measurements were taken, each with decreasing range (increasing water level), represented by separate colors shown in Figure 3-2. The COMPIN signal was probed with an oscilloscope and the data below is overlayed for each measurement. The START and corresponding STOP pulses are shown below the COMPIN plot. STOP pulses are corresponding in time with their respective COMPIN return echo. COMPIN signals are overlayed for visual comparison, and the data is trimmed after the return pulse to avoid visual data overlap. The START pulse is at time t=0 in yellow.

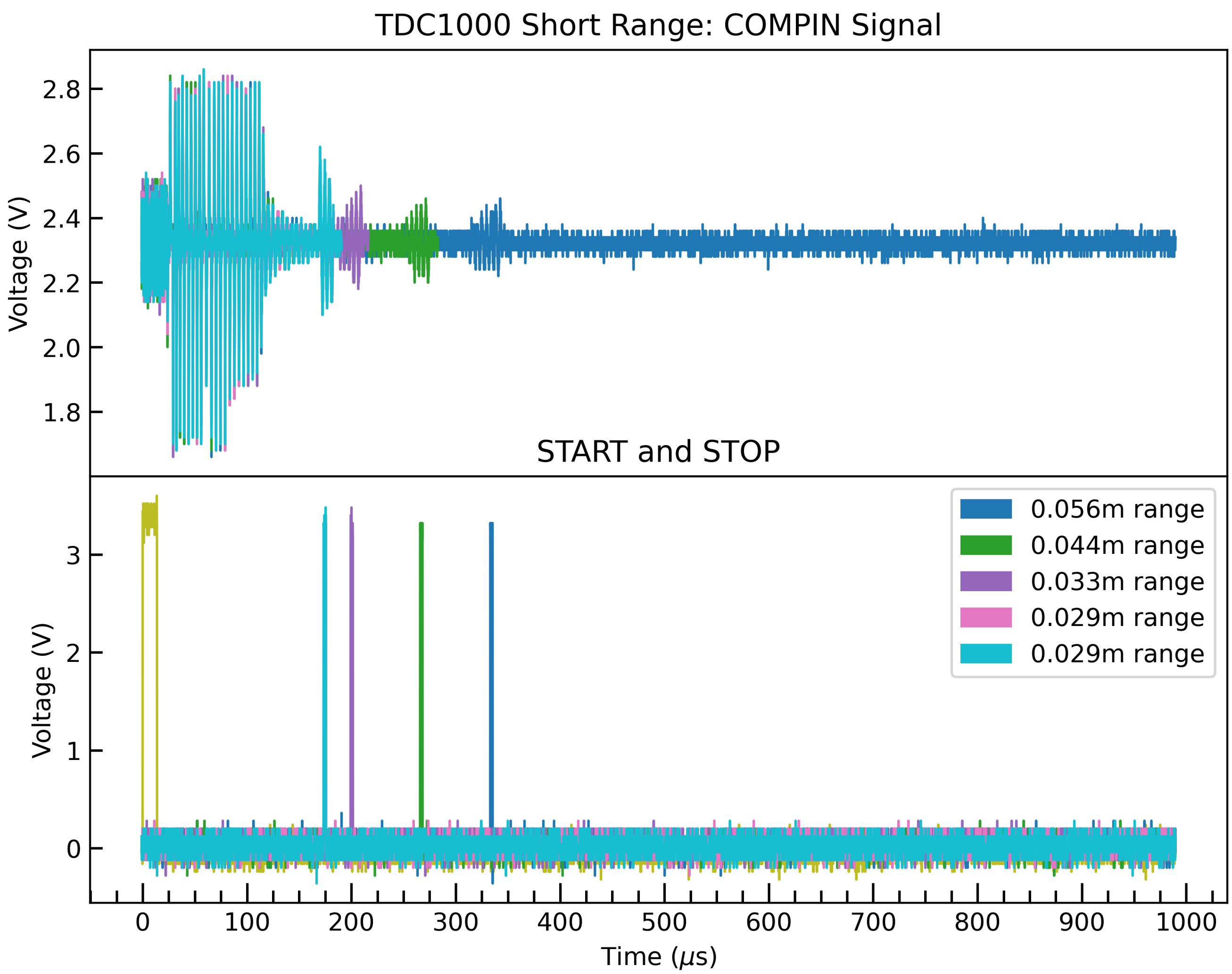


Figure 3-2. Short Range Air-Coupled Results: TDC1000

In the TDC1000 short measurement mode, the minimum range is determined directly by the burst pulse time, blanking time, and TX ringing decay time. The blanking time is set to delay the listen period until just after the transducer ringing falls below ECHO_QUAL_THLD. The above results show that the blanking time was set to delay the listen period until approximately 175 µs, determined such that false STOP pulses triggered by ringing noise would be avoided. Notice that the pink and teal COMPIN signals both are measured at the beginning of the listen period and have a flat leading edge envelope compared to the other data. This happens when the return pulse is partially cut off by the blanking period. A partial echo such as this must be discarded because it does not represent the true ToF. To ensure a true measurement, some margin between the blanking period end and the minimum ToF measurement may be needed. Discarding the last measurement here, the minimum ToF accurately measured with this setup was at a 3.3cm distance from water level to transducer.

4 Mid-Range Air-Coupled Test Results

This mid-range test compares the versatility of the TUSS4470 and TDC1000 in air-coupled evaluation. For the TUSS4470 5 V VDRV tests shown below, the short range device settings are retained to show the full range achievable with this 220 kHz setup. For the TUSS4470 35V VDRV test, device power settings were altered to accommodate the external voltage provided. TDC1000 mid-range testing was performed in the standard ToF measurement mode.

4.1 TUSS4470

4.1.1 Concept

Similar to the short range test, this measurement range was approximated and then four measurements were taken to show a progression towards the end of the range. The threshold method discussed above was used to compute the ToF on a single return echo pulse seen on VOUT. The threshold crossing is marked on the first plot.

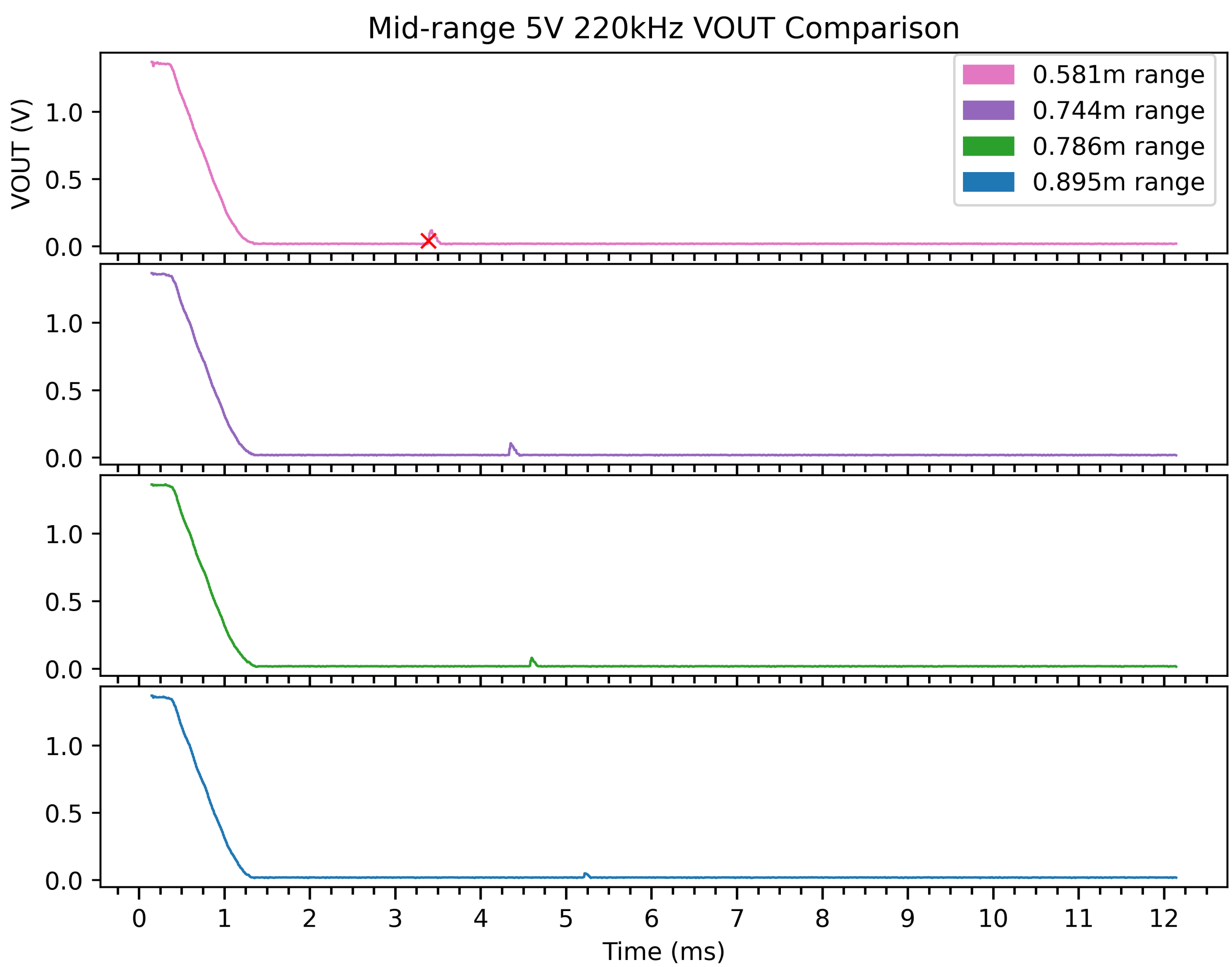


Figure 4-1. Mid-Range Air-Coupled Results: TUSS4470

This test shows a range up to about 0.895m. The full useful range for an application ultimately depends on the tolerable SNR and reliability of the measurement.

4.1.2 TUSS4470 35 V Results

The 5 V mid-range test was repeated with the TUSS4470 configured for 35 V to be applied on VDRV. The resulting VOUT plots were recorded and shown in Figure 4-2.

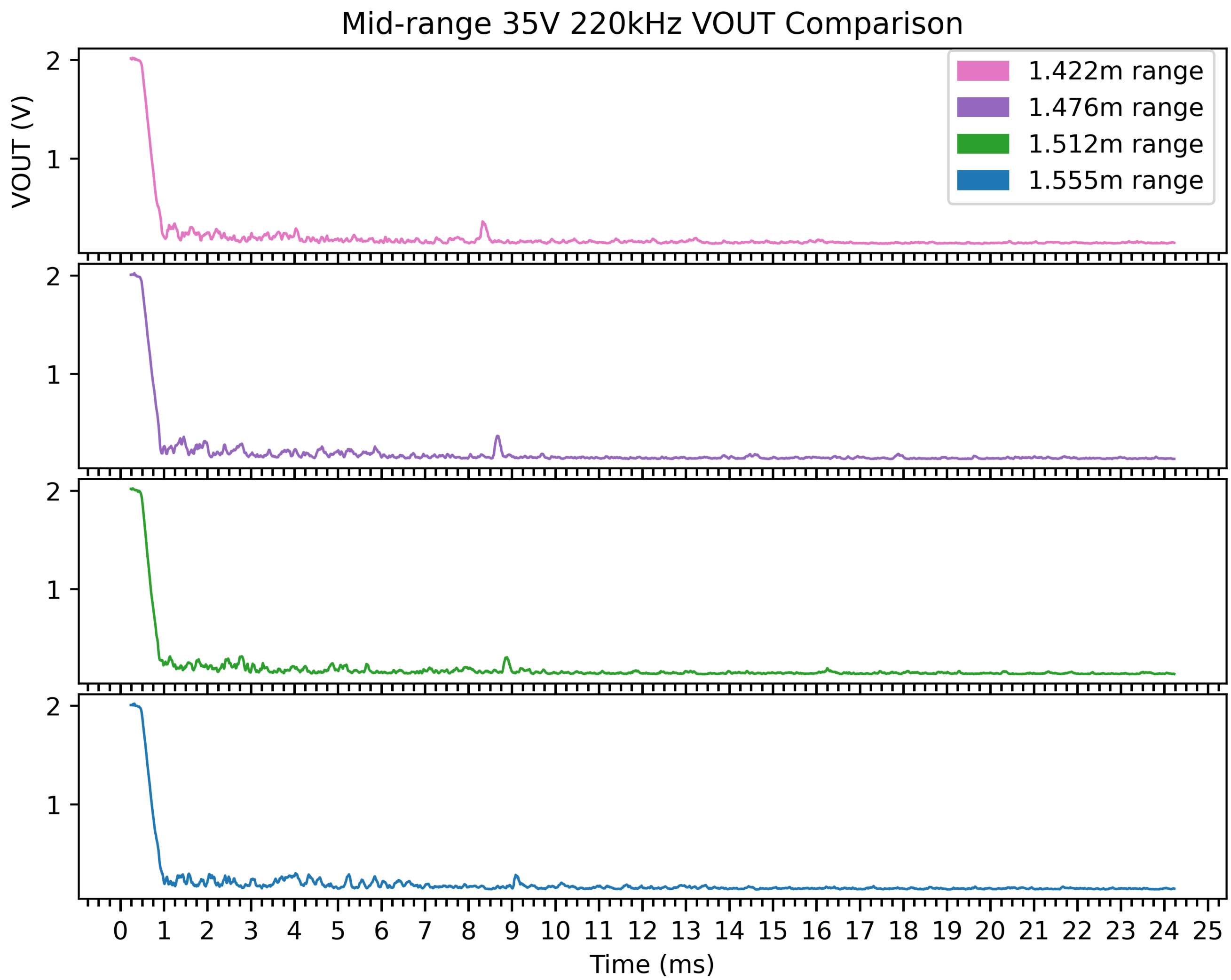


Figure 4-2. Mid-Range Air-Coupled Results: TUSS4470

The 35 V transmit voltage increases the range considerably. The SNR is not quite as favorable as the 5 V test shows. Enabling the log-amp stages did not visually increase the SNR, so to provide a better comparison to the 5 V test the log amp was disabled. As before, the ToF calculation depended on a threshold crossing, which was more difficult with a lower SNR.

4.2 TDC1000

A series of measurements was taken to experimentally determine the upper distance boundary. CH1: START, CH2: COMPIN, CH3: STOP.

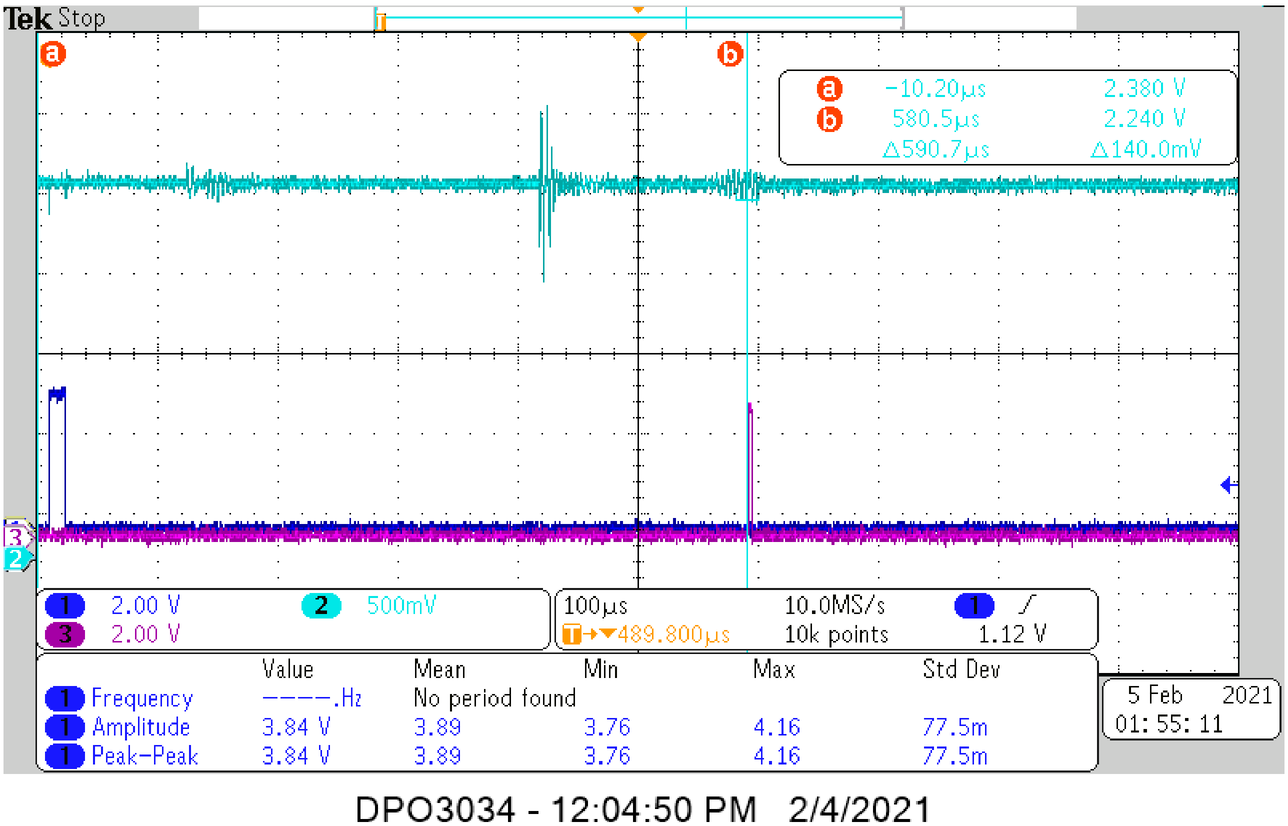


Figure 4-3. Mid-Range Air-Coupled Results: TDC1000

The standard ToF measurement mode was used in anticipation of a longer ToF, however, it was not necessary. Since the maximum range is limited by echo attenuation, a similar result would be seen in short ToF mode. In the standard mode, noise is seen on the COMPIN pin during the auto-zero period, this should not be mistaken for the received echo. The end of the reliable range was found to be about 10cm. Just beyond 10cm, the signal is too weak to be reliably trigger a stop pulse with the 35 mV threshold.

In Figure 4-4, the signal is too weak to trigger a stop.

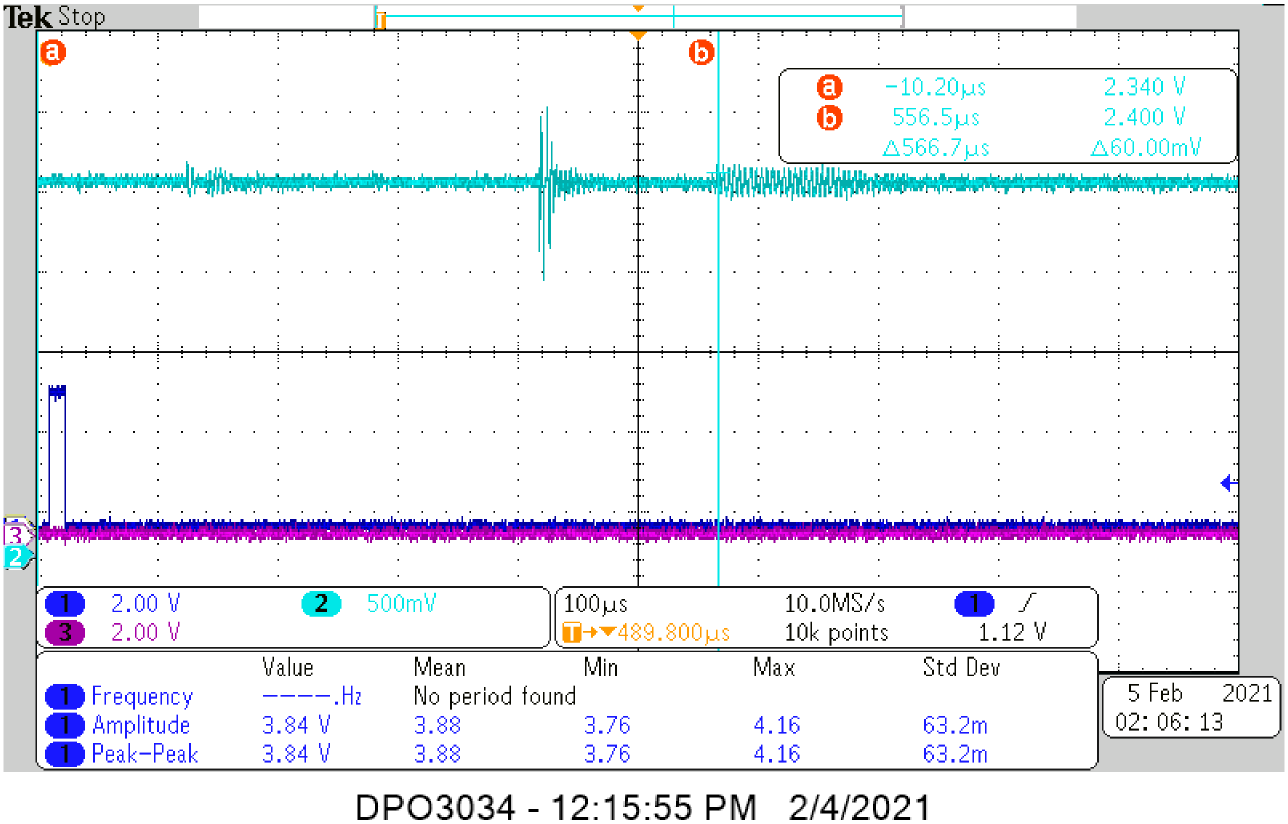


Figure 4-4. Mid-Range Air-Coupled Results: TDC1000

5 Short Range Water-Coupled Test Results

5.1 TUSS4470

The water level in a small acrylic tank was adjusted for four measurements of decreasing water level. The 1 MHz Steminc transducer was used as described in Section 2.2. At this transducer frequency, using an oscilloscope to view VOUT is recommended over the MSP430F5529LP ADC and GUI display.

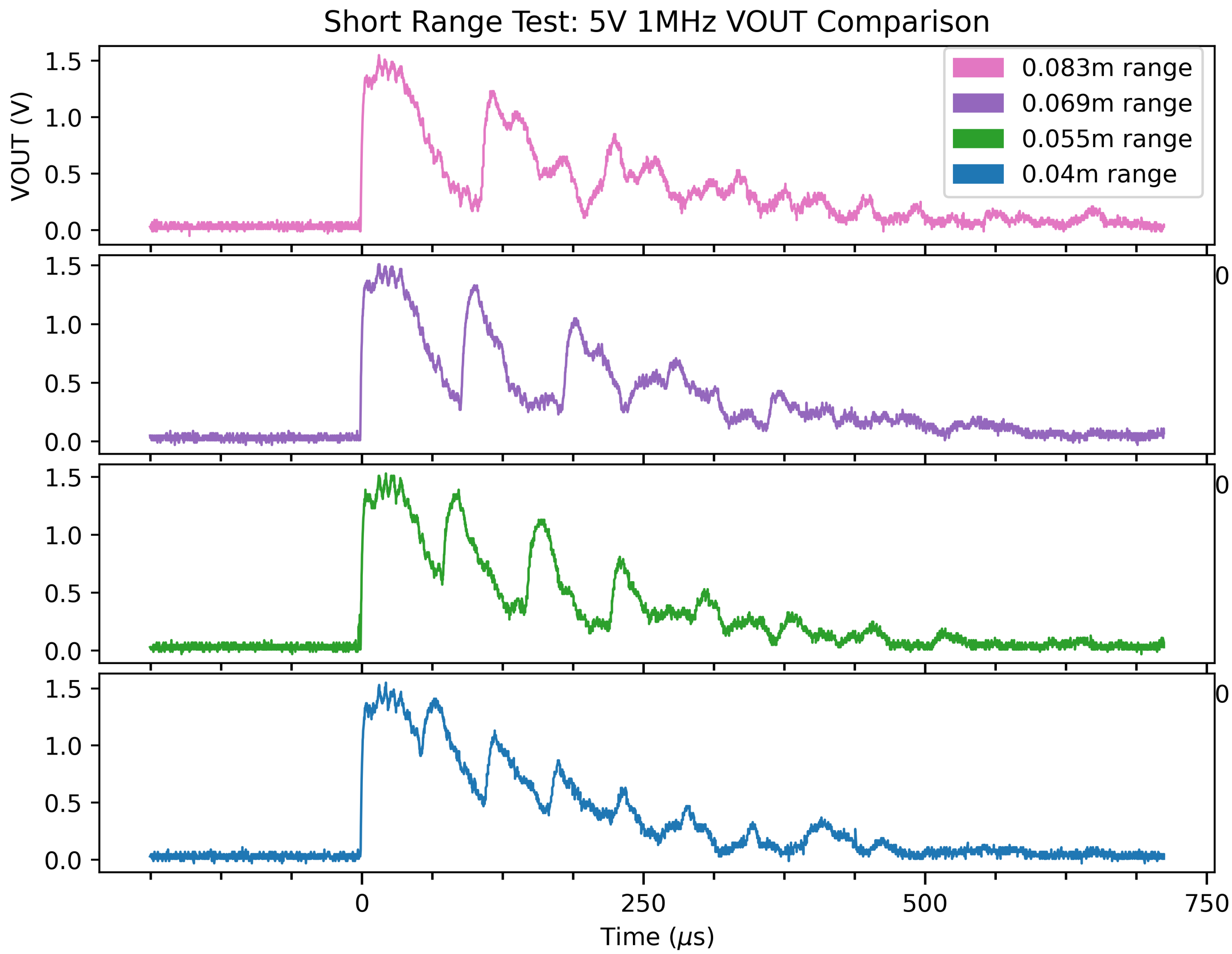


Figure 5-1. Short Range Water-Coupled Results: TUSS4470

The ToF was computed in post processing using a threshold comparison on the TX pulse and first received echo shown on VOUT. Subsequent echo pulses show the decaying ultrasonic echo reflection, also seen in the short range air-coupled data. The minimum deletable water level with this method was 4cm.

5.2 TDC1000

TDC1000 acrylic tank water level minimum ToF measurement. CH1: TX, CH2: COMPIN, CH3: STOP.

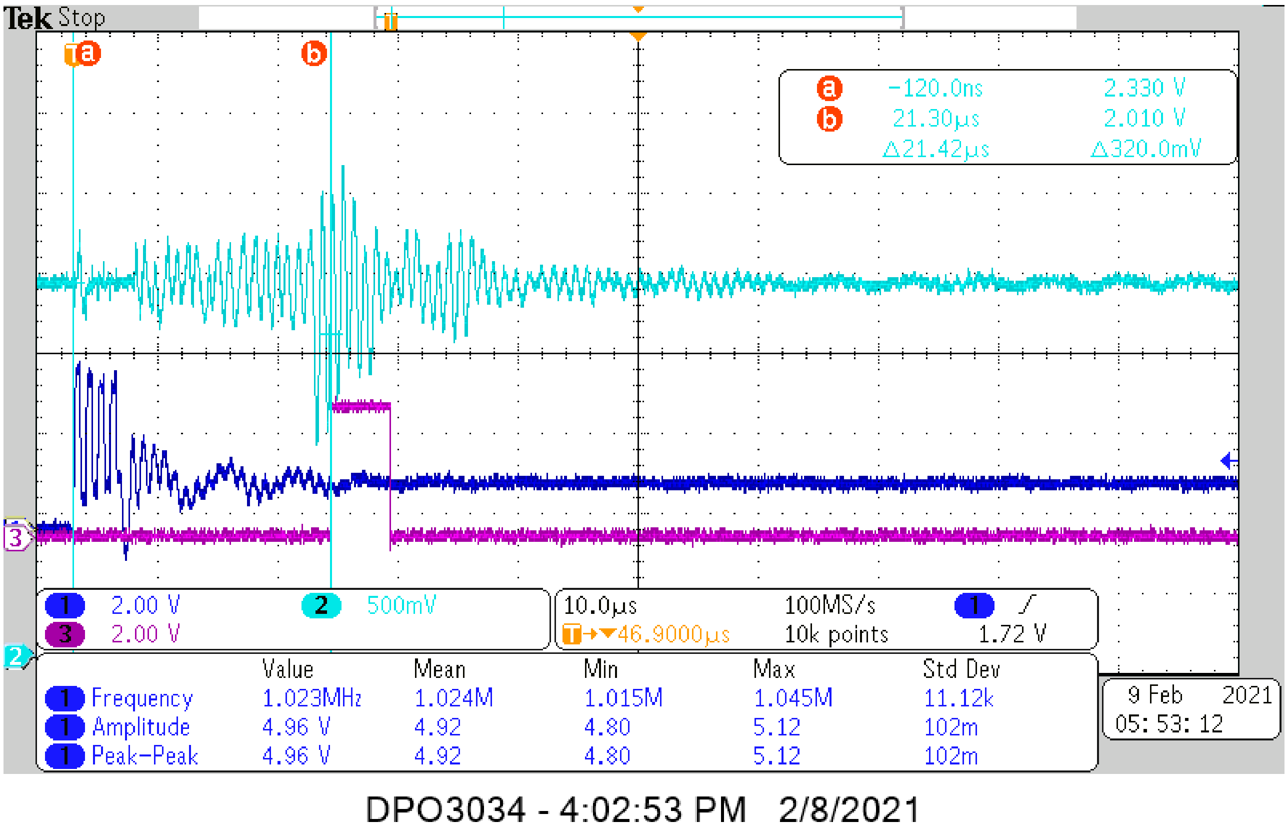


Figure 5-2. Short Range Water-Coupled Results: TDC1000

The minimum detectable ToF shown here is close to 20 µs as expected, since the minimum measurable ToF possible with this TDC1000 configuration is (4 × T1 + 128 × T0). Note that the minimum accurately detectable ToF is slightly higher than the minimum ToF possible, hence characterizing the minimum per device and application is always advised. The ToF measured here corresponds to approximately 3.1cm in water.

6 Resistive Damping Device Comparison

This section compares the selection and tradeoffs of installing a damping resistor in parallel with a 1 MHz transducer to reduce the minimum possible range. The water-coupled acrylic tank level measurement test fixture was used.

6.1 TUSS4470

Figure 6-1 shows the TUSS4470 VOUT signal: undamped, 500Ω damped, and 75Ω damped, respectively. Cursors show the distance between the TX pulse and the first return echo pulse. To quantify the damping effect, cursor 'a' is placed to cross VOUT on the TX pulse approximately at the voltage level bisecting min and max of the leading edge of the first return pulse. Another helpful measure could be taken from the start of the TX decay until the first rising edge.

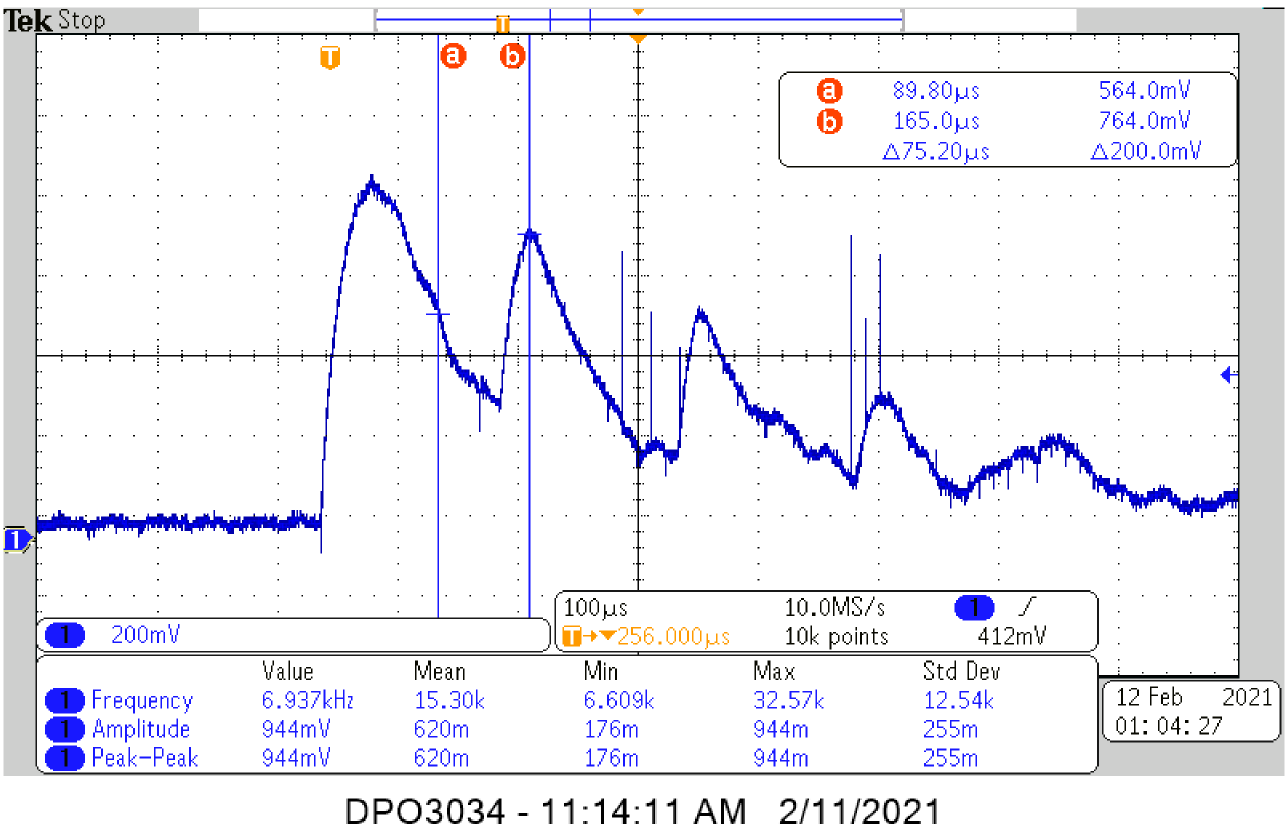


Figure 6-1. TUSS4470 1MHz Water Level Measurement: Undamped

Figure 6-2 shows a 10 kΩ potentiometer soldered in parallel to the transducer across J3 on the TUSS4470EVM provided the adjustable damping resistance.

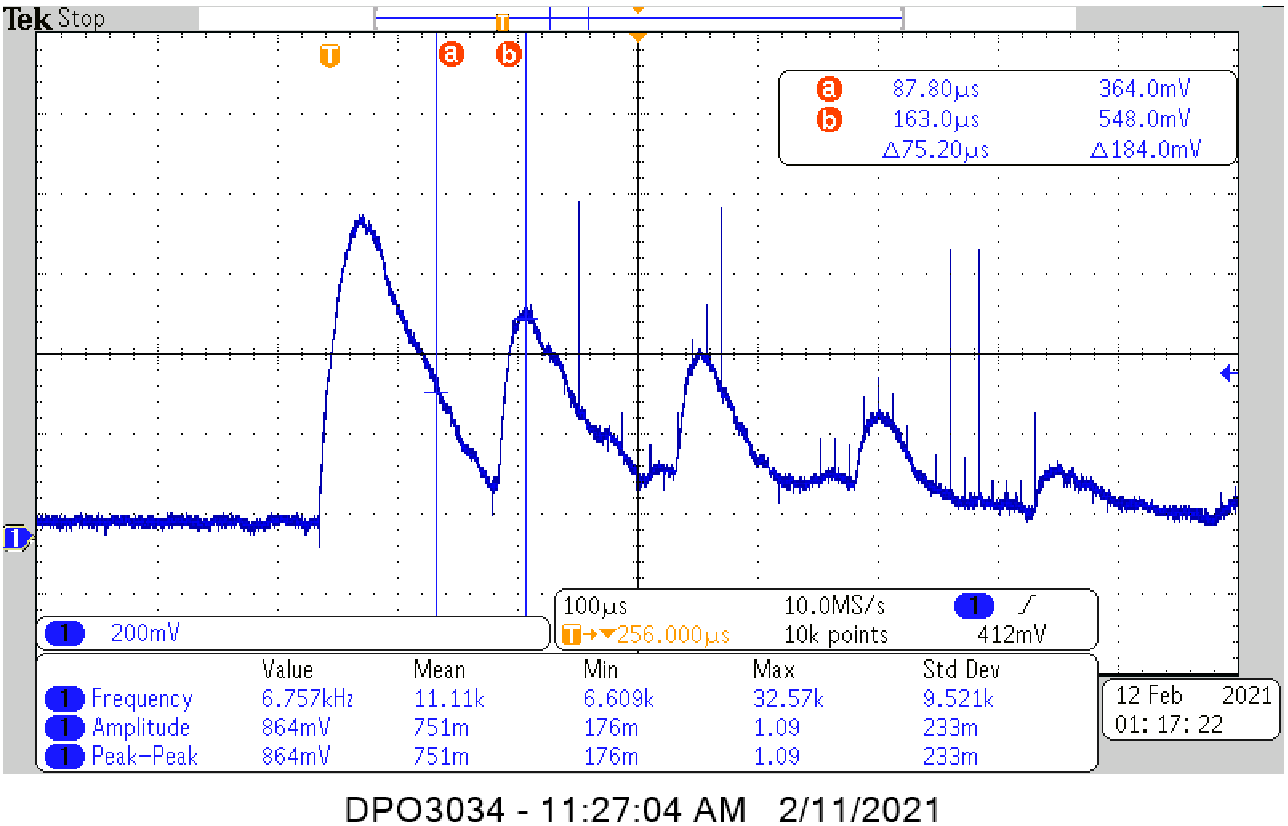


Figure 6-2. TUSS4470 1 MHz Water Level Measurement: 500Ω damping

Figure 6-3 compares the constant ToF measurements, the damped measurements show a quicker decay before the first echo pulse arrives as the resistance is decreased. The timing metric used here also increases from 75.2 μs to 93.2 μs, illustrating that the minimum range will be somewhat improved with resistive damping. The drawbacks to resistive damping are reduced range or increased current consumption from the increased load on the transducer driver.

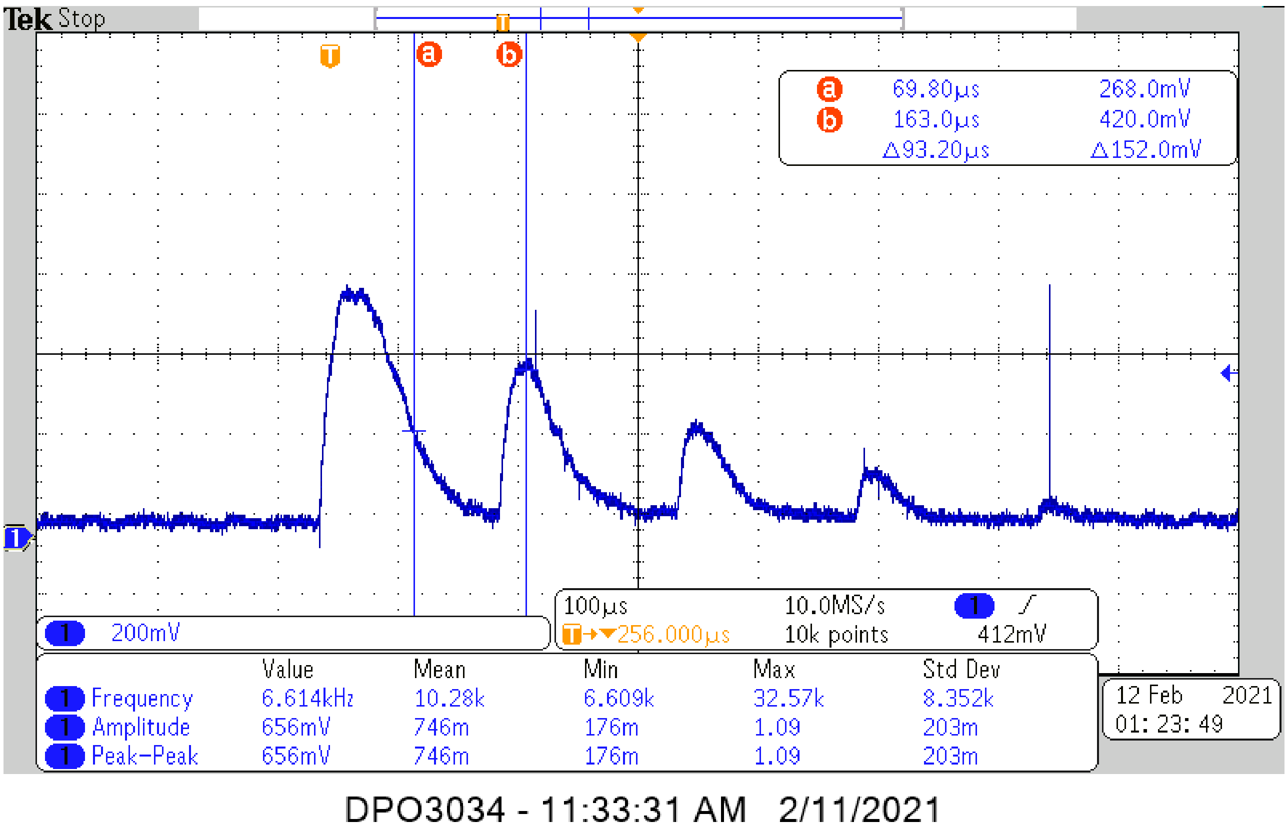


Figure 6-3. TUSS4470 1 MHz Water Level Measurement: 75Ω damping

6.2 TDC1000

To show the effect of the damping resistor, TX (CH1), COMPIN (CH4), START (CH2), and STOP (CH3) are shown in three ToF level measurement plots using 10 kΩ, 1250Ω, and 150Ω damping. Without damping, a 16 µs blanking period is enough to mask the ring down disturbance to COMPIN, thus an 8 µs blanking period was used to allow for an improvement in the minimum measurement range to be observed.

The noise on COMPIN matches up with the TX decay as expected, and this leads to false STOP generation just after the 8 µs blanking period ends.

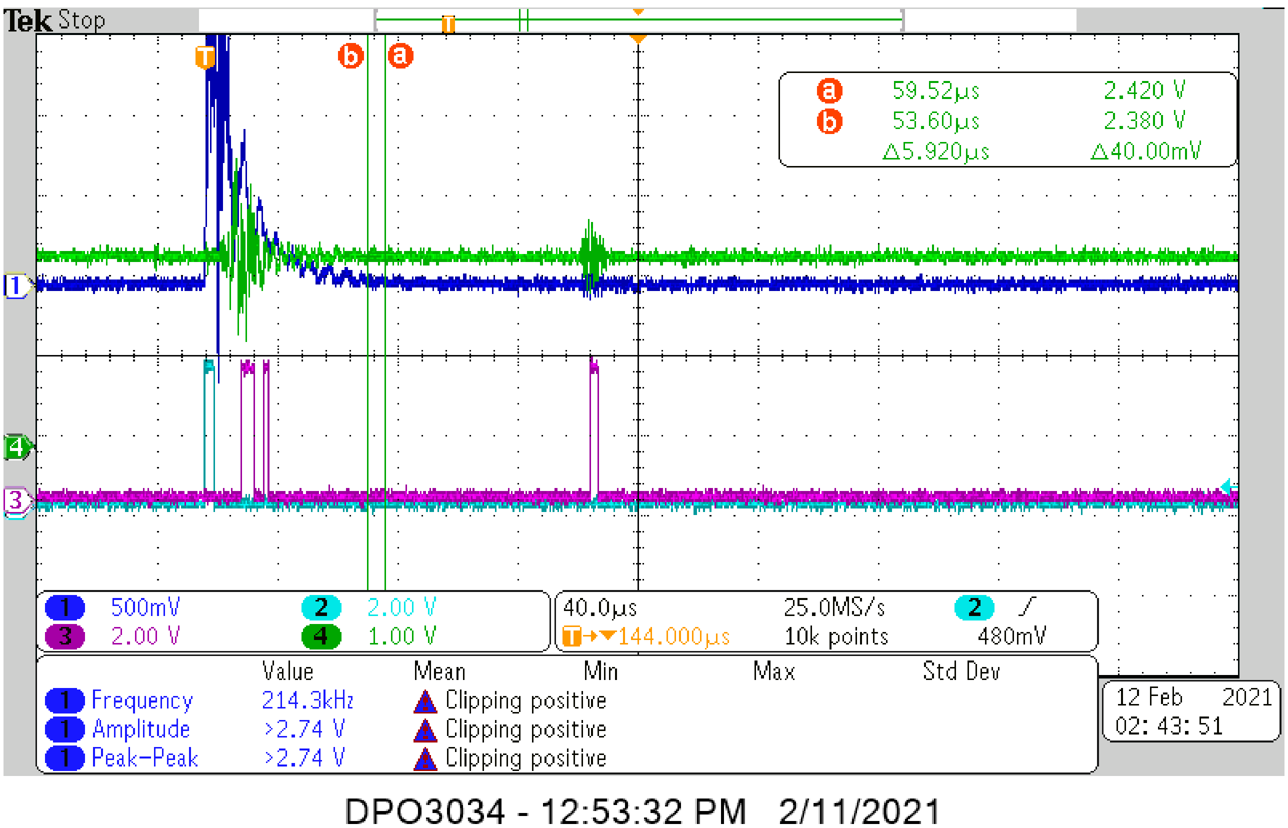


Figure 6-4. TDC1000 1 MHz Water Level Measurement: 10kΩ Damping

The noise is still large enough to trigger an early STOP, however the TX decay is shorter.

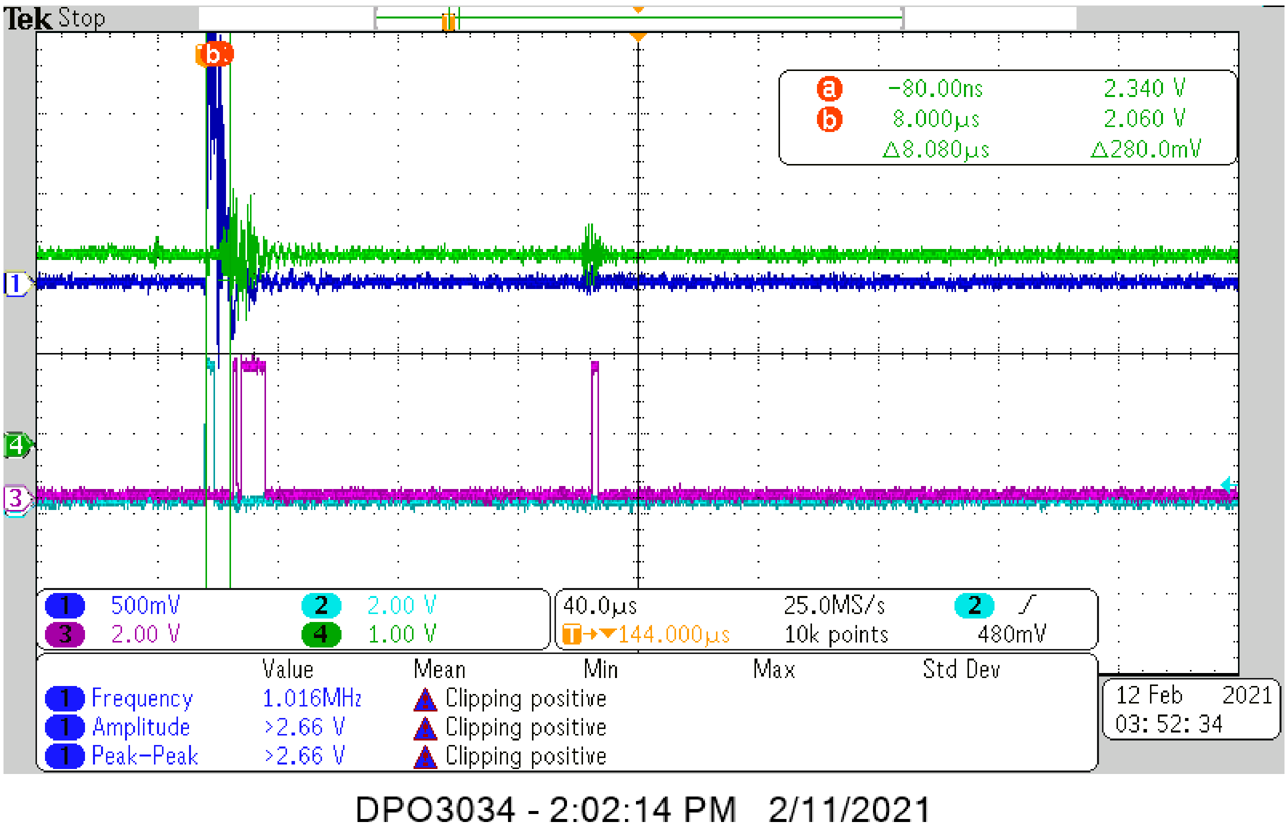


Figure 6-5. TDC1000 1 MHz Water Level Measurement: 1.25kΩ Damping

Here, the TX decay is truncated nicely, but the return echo is also attenuated below the threshold. In short range liquid measurements, the gain can often be increased enough to generate a STOP, yet this may only improve the short range performance if the ratio between return echo amplitude and the TX noise amplitude is greater than one. Since both and noise and echo will be attenuated similarly, the TDC1000's threshold detection method is not as conducive to this resistive damping technique.

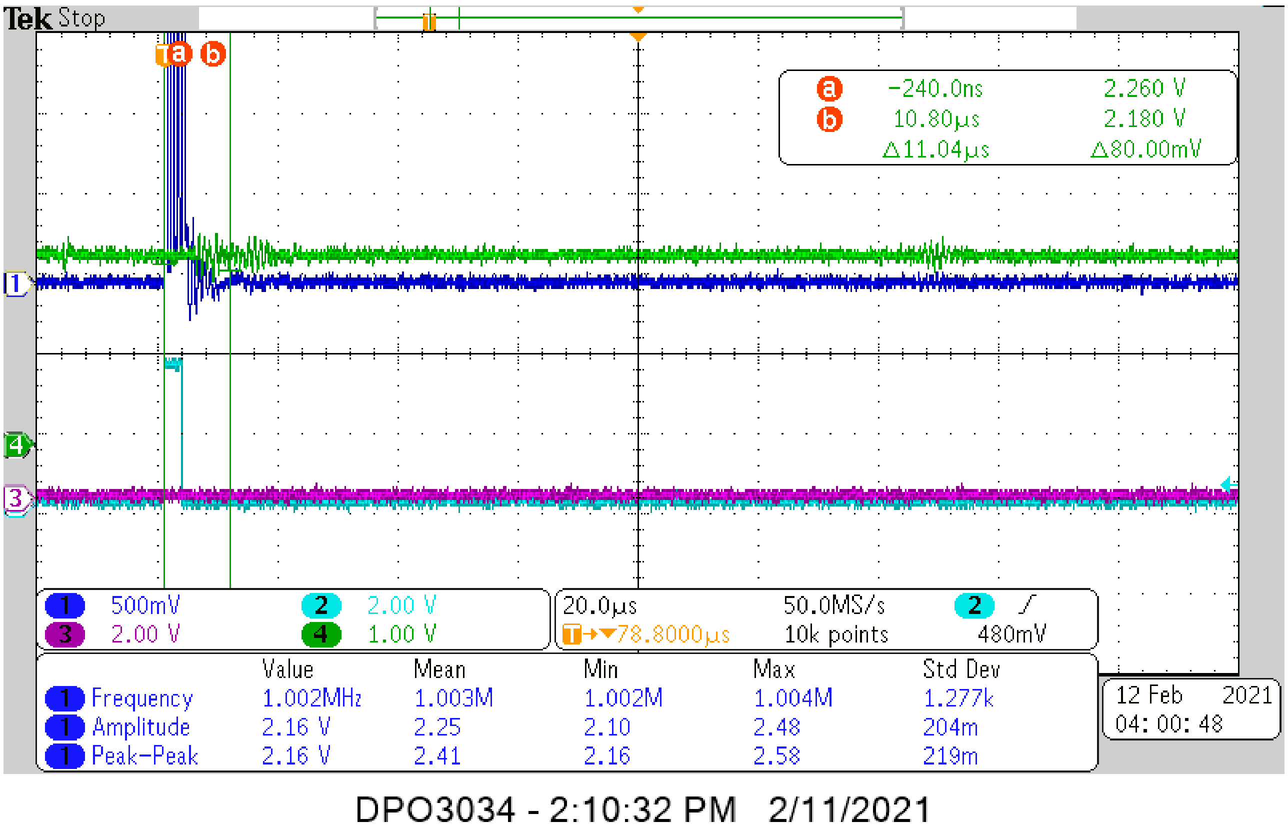


Figure 6-6. TDC1000 1 MHz Water Level Measurement: 150Ω Damping

7 Summary

This water-coupled and air-coupled water level sensing comparison between the TUSS4470 and TDC1000 highlights aspects of device evaluation, performance, and versatility. Overall, the TUSS4470 proved easier to use, and a more versatile device in air and water coupled applications due to the upgraded EVM design, versatile transducer driver topology enabling a wide transmit voltage range, and the VOUT envelope RX output. Resistive damping also showed higher potential for improving performance with the TUSS device. Although a threshold triggered interrupt is also available on the TUSS4470, using ADC sampling to determine ToF gives more control to the developer versus the TDC1000's threshold triggered stop time method, which could translate to improved short range performance. The wider air-coupled measurement range shown with the TUSS4470 demonstrated superiority in air-coupled applications compared to the TDC1000. Both the TDC1000 and TUSS4470 performed similarly in the water-coupled tests. The TDC1000 may be preferred in some water and solid-coupled ToF measurement applications due to it's high frequency transducer comparability.

8 References

1. Texas Instruments: *Ultrasonic Sensing Basics*
2. Texas Instruments: *Using Ultrasonic Sensing to Monitor Level in Tanks*
3. Texas Instruments: *PGA460 Ultrasonic Module Hardware and Software Optimization*
4. Texas Instruments: *How to Select and Mount Transducers in Ultrasonic Sensing for Level Sensing and Fluid ID*
5. Texas Instruments: *TUSS4470 Direct Drive Ultrasonic Sensor IC With Logarithmic Amplifier Data Sheet*
6. Texas Instruments: *TUSS44x0 EVM for Ultrasonic Sensors User's Guide*
7. Texas Instruments: *TDC1000 Ultrasonic Sensing Analog Front End (AFE) for Level Sensing, Flow Sensing, Concentration Sensing, and Proximity Sensing Applications Data Sheet*
8. Texas Instruments: *TDC1000-C2000EVM User’s Guide*
9. TUSS4470 TI Precision Labs Video Series
10. Ultrasonic AFE Comparison

A Appendix A

A.1 TUSS4470: Filter Capacitor Selection

Freq (kHz)	CINN (nF)	CFLT (nF)
30	141.4710605	21.22066
40	106.1032954	15.91549
50	84.88263632	12.7324
60	70.73553026	10.61033
70	60.63045451	9.094568
80	53.0516477	7.957747
90	47.15702018	7.073553
100	42.44131816	6.366198
110	38.58301651	5.787452
120	35.36776513	5.305165
130	32.64716781	4.897075
140	30.31522726	4.547284
150	28.29421211	4.244132
160	26.52582385	3.978874
170	24.96548127	3.744822
180	23.57851009	3.536777
190	22.33753587	3.35063
200	21.22065908	3.183099
210	20.2101515	3.031523
220	19.29150825	2.893726
230	18.45274703	2.767912
240	17.68388257	2.652582
250	16.97652726	2.546479
260	16.32358391	2.448538
270	15.71900673	2.357851
280	15.15761363	2.273642
290	14.6349373	2.195241
300	14.14710605	2.122066
310	13.69074779	2.053612
320	13.26291192	1.989437
330	12.8610055	1.929151
340	12.48274063	1.872411
350	12.1260909	1.818914
360	11.78925504	1.768388
370	11.47062653	1.720594
380	11.16876794	1.675315
390	10.88238927	1.632358
400	10.61032954	1.591549
410	10.35154101	1.552731
420	10.10507575	1.515761
430	9.87007399	1.480511
440	9.645754127	1.446863
450	9.431404035	1.414711
460	9.226373513	1.383956
470	9.030067693	1.35451
480	8.841941283	1.326291
490	8.661493502	1.299224
500	8.488263632	1.27324
510	8.32182709	1.248274
520	8.161791953	1.224269
530	8.007795879	1.201169
540	7.859503363	1.178926
550	7.716603301	1.15749
560	7.578806814	1.136821
570	7.445845291	1.116877
580	7.317468648	1.09762
590	7.193443756	1.079017
600	7.073553026	1.061033

Figure A-1. TUSS4470EVM Capacitor Selection Table

610	6.957593141	1.043639	810	5.239668908	0.78595
620	6.845373896	1.026806	820	5.175770507	0.776366
630	6.736717168	1.010508	830	5.113411826	0.767012
640	6.631455962	0.994718	840	5.052537876	0.757881
650	6.529433563	0.979415	850	4.993096254	0.748964
660	6.430502751	0.964575	860	4.935036995	0.740256
670	6.334525098	0.950179	870	4.878312432	0.731747
680	6.241370317	0.936206	880	4.822877063	0.723432
690	6.150915675	0.922637	890	4.768687433	0.715303
700	6.063045451	0.909457	900	4.715702018	0.707355
710	5.977650445	0.896648	910	4.663881116	0.699582
720	5.894627522	0.884194	920	4.613186756	0.691978
730	5.8138792	0.872082	930	4.563582598	0.684537
740	5.735313265	0.860297	940	4.515033847	0.677255
750	5.658842421	0.848826	950	4.467507175	0.670126
760	5.584383968	0.837658	960	4.420970641	0.663146
770	5.511859501	0.826779	970	4.375393625	0.656309
780	5.441194636	0.816179	980	4.330746751	0.649612
790	5.372318754	0.805848	990	4.287001834	0.64305
800	5.30516477	0.795775	1000	4.244131816	0.63662

Figure A-2. TUSS4470EVM Capacitor Selection Table (Continued)

A.2 TUSS4470: Shematic

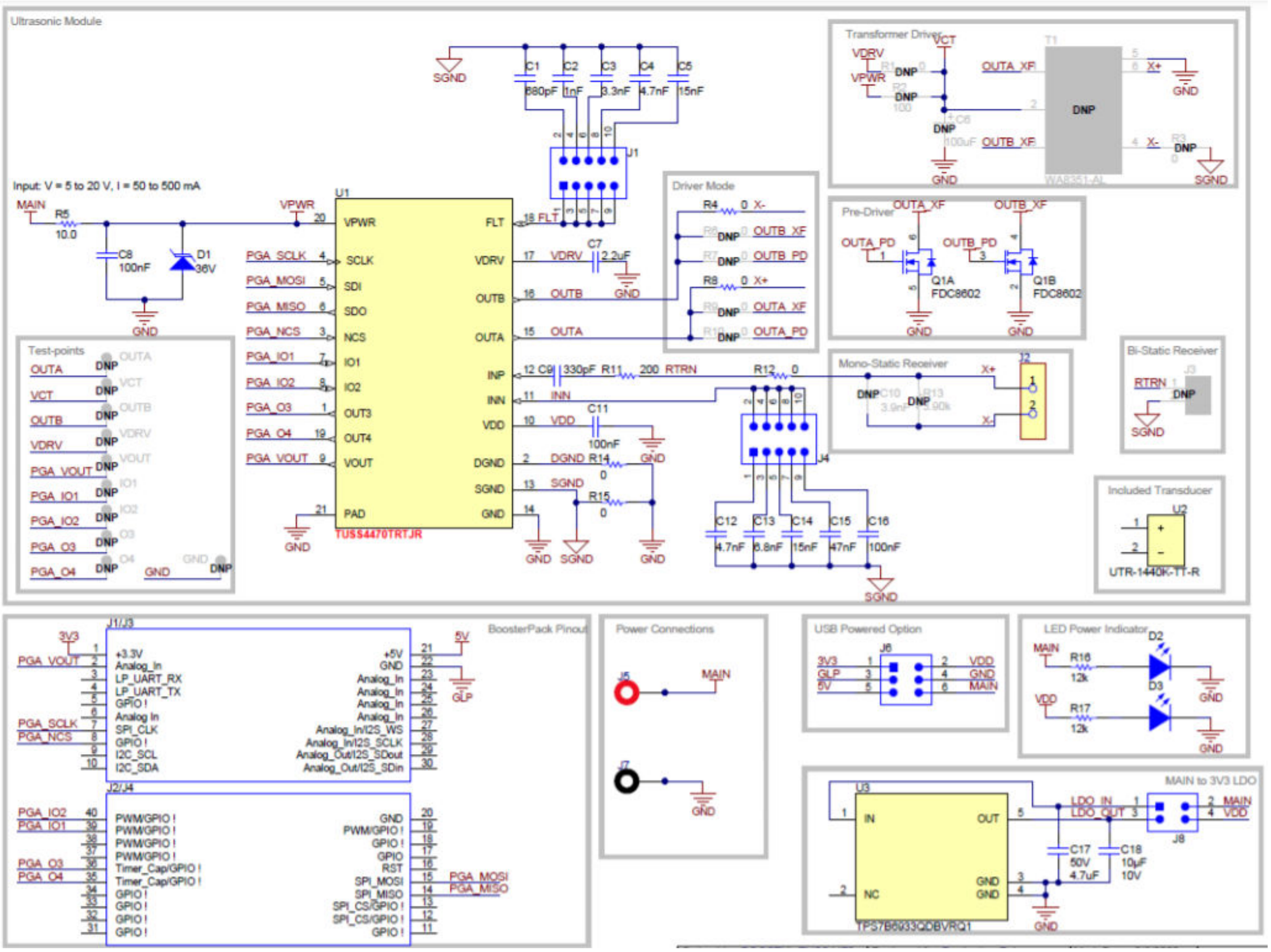


Figure A-3. BOOSTXL-TUSS4470 Schematic

B Appendix B

B.1 TDC1000 Misc.

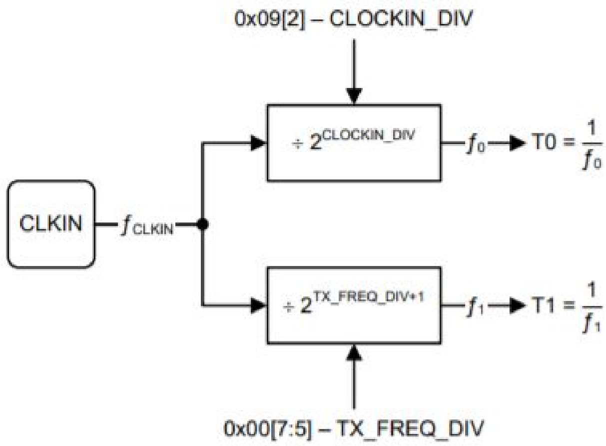
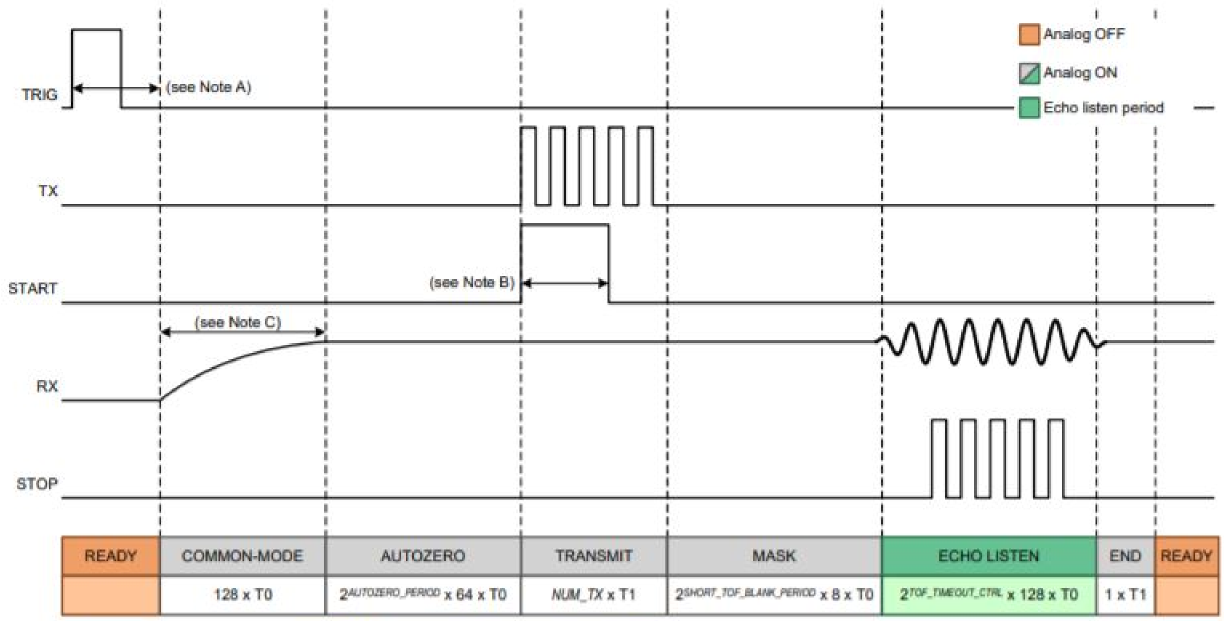


Figure B-1. T0 and T1 Definition

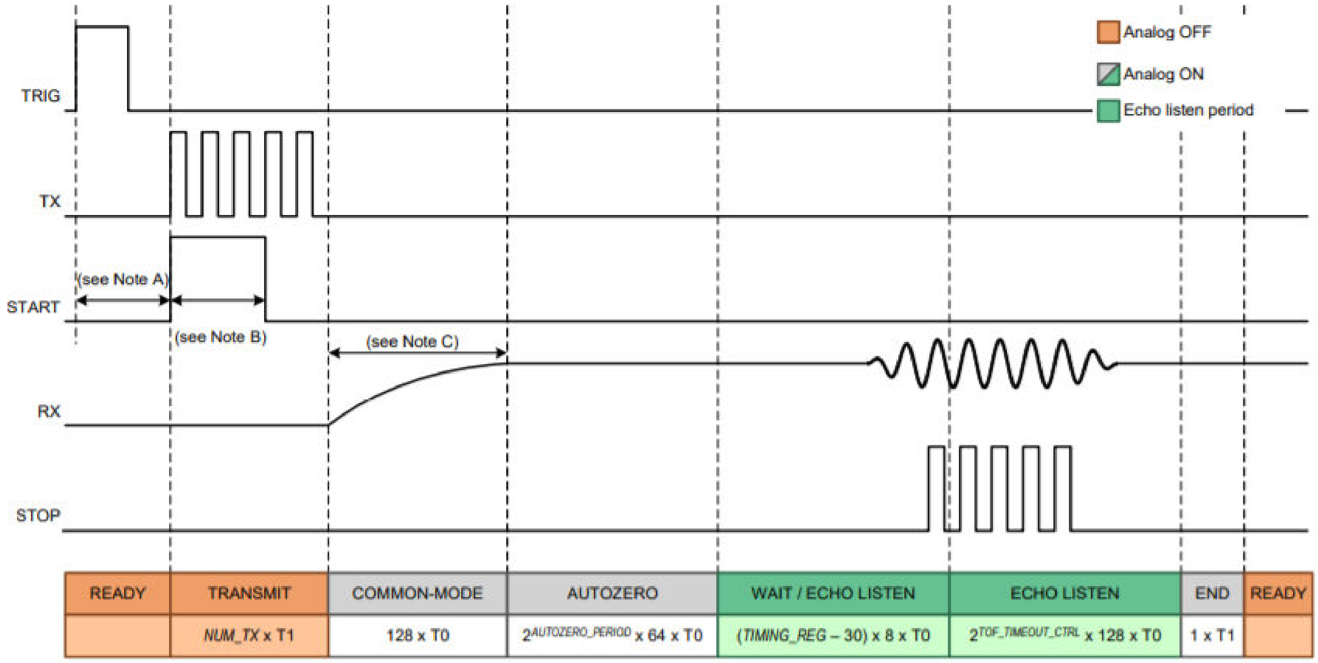


A. Clock alignment (see TX/RX Measurement Sequencing and Timing)

B. If *NUM_TX* < 3, the width of the START pulse is equal to *NUM_TX* × T1. If *NUM_TX* ≥ 3, the width of the START pulse is equal to 3 × T1.

C. Common-mode settling time.

Figure B-2. Short ToF Measurement Device Configuration Graphic



A. Clock alignment (see TX/RX Measurement Sequencing and Timing)

B. If *NUM_TX* < 3, the width of the START pulse is equal to *NUM_TX* × T1. If *NUM_TX* ≥ 3, the width of the START pulse is equal to 3 × T1.

C. Common-mode settling time.

Figure B-3. Standard ToF Measurement Device Configuration Graphic

B.2 TDC1000-C2000EVM Schematic

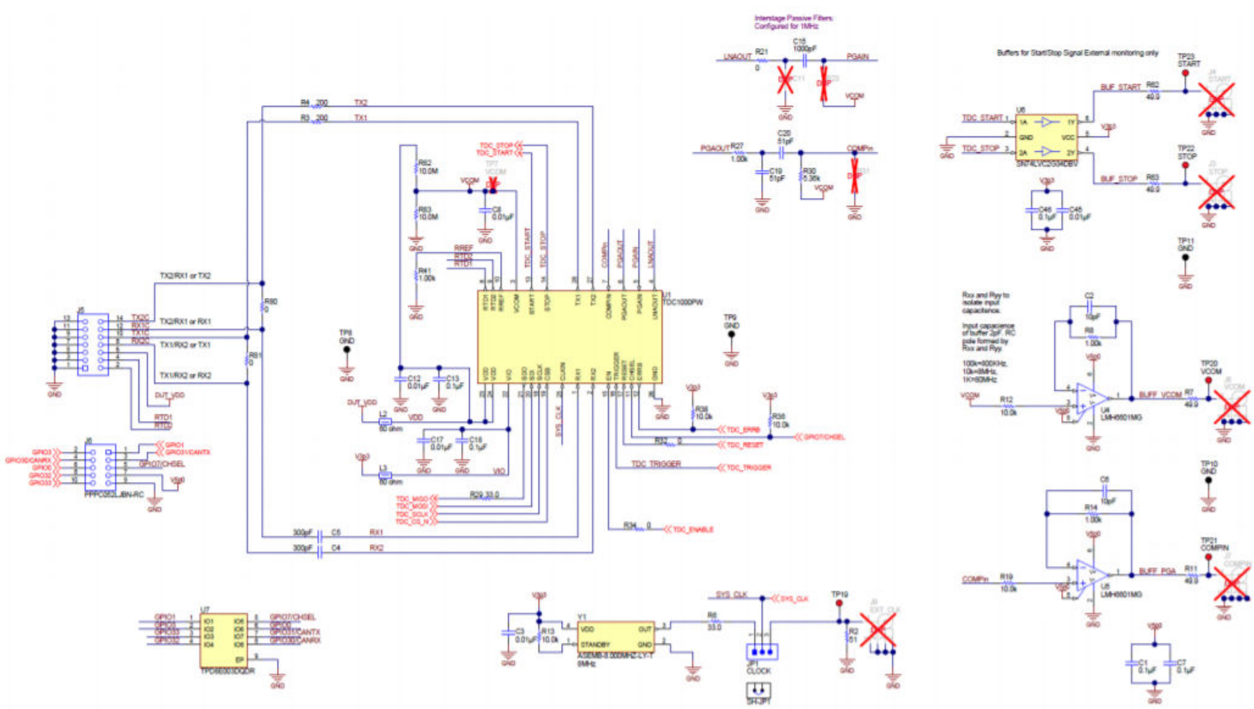


Figure B-4. TDC1000-C2000EVM Partial Schematic