TI Designs: TIDA-01597
Automotive Ultrasonic Sensing Module Reference Design for Park Assist

TEXAS INSTRUMENTS

Description

This reference design provides hardware architecture for a Park Assist System (PAS) using three highly-integrated, system-on-chip (SoC) ultrasonic transducer drivers. These ultrasonic transducer drivers have an integrated signal conditioner with an advanced digital signal processor (DSP) core. Using these integrated features, object detection from 25 cm to 2.5 m is achieved. The distance data is sent over a one-wire interface (OWI) to a local electronics control unit (ECU) where the data can be aggregated and processed. The sensor initialization, object detection algorithm, and software described in this design guide provide a basic framework to help engineers working on PAS for automotive or collision avoidance.

Resources

TIDA-01597	Design Folder
PGA460-Q1	Product Folder

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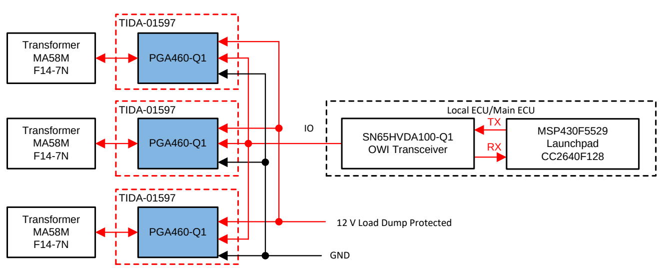
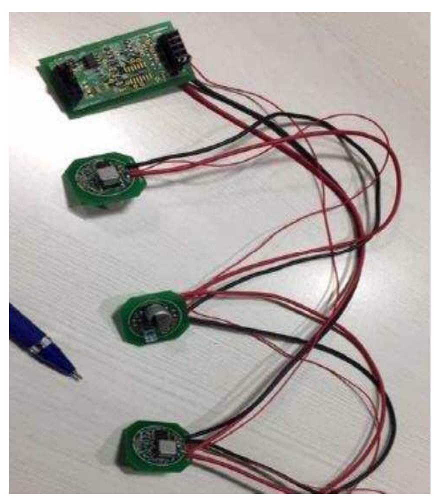
Features

- Combines Three PGA460-Q1 Devices to Detect Objects From 25 cm to 2.5 m
- Provides System Diagnostic Information
- Circuitry for Level USART and TCI Interface Option Included
- 22-mm Diameter Solution Size

Applications

- Ultrasonic Park Assist
- Collision Avoidance





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1 System Description

To detect an object behind the car during reverse motion, a park assist system should cover the entire rear side and blind spots. For the low-cost implementation in this reference design, a three-sensor system is used. However, the same concept can easily be extended to four sensors.

For PAS, the maximum detection range requirement from the vehicle can extend up to 1.5 m or 2 m. In addition, it is also important to be able to detect objects at very close distances, less than 20 cm from vehicle. Object distance information is then sent over OWI to an ECU where data is aggregated.

In the case of the rear sonar, two to four transformer-driven ultrasonic sensors are mounted on the rear bumper to detect an obstacle up to 2 to 2.5 m away. The main characteristics of ultrasonic sensors for rear sonar are directivity, ringing time, sensitivity and sound pressure. Directivity of an ultrasonic sensor corresponds to the size and shape of the vibrating surface (that is, emitting the ultrasound) and the frequency at which it vibrates.

Being an automotive application, it is also important to have a solution which can provide sensor diagnostic information. The solution should also detect and report failures of individual sensors for passenger safety. Here, the PGA460-Q1 device can provide sensor, supply, and transceiver diagnostics.

2 System Overview

2.1 Block Diagram

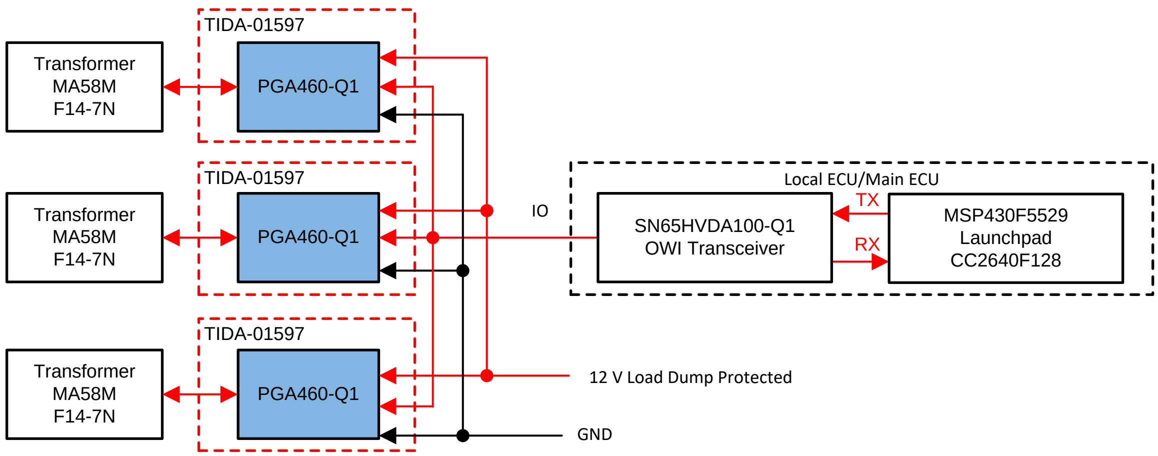

Figure 1. TIDA-0597 Block Diagram

2.2 Design Considerations

Table 1 and Figure 2 show the average dimensions of a car. The width of an average car is within 1.5 m to 1.75 m. As mentioned before, to detect an object behind the car during reverse motion, the park assist solution should cover the entire rear side and blind spots.

Table 1. Example Dimensions of Car

Dimensions	(m)
Length	3.85
Width	1.7
Height	1.53
Ground Clearance	0.17

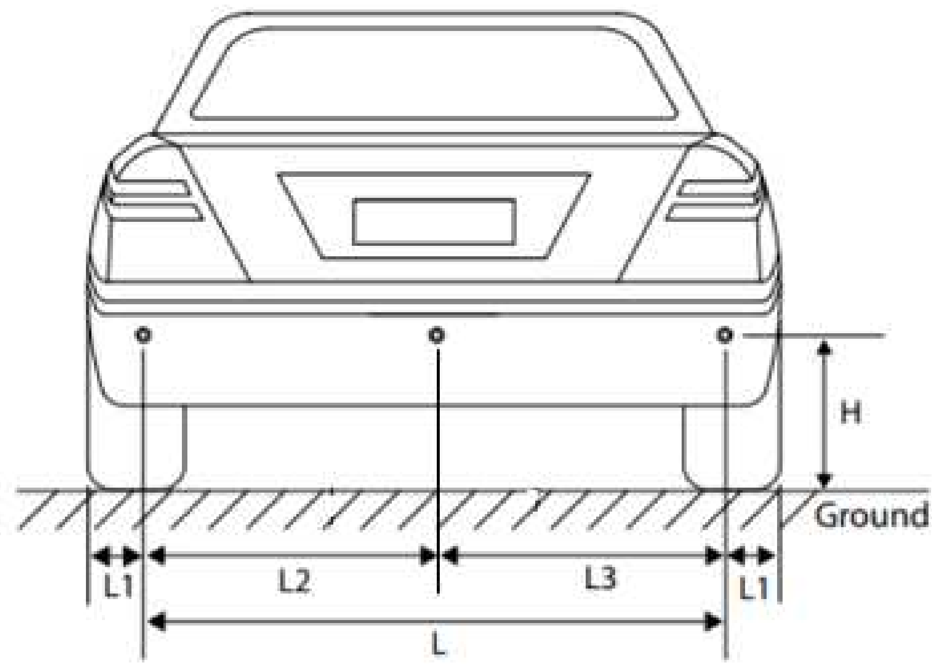

Figure 2. Car Dimensions

As an example of an actual system, consider a car that is 1.7 m wide. Referring to Figure 2, L1 + L2 + L3 + L1 = 1.7 m. If L1 = 0.1 m, then the distance between the adjacent sensors, L2 = L3 = 0.75 m and the approximate height of sensor placement is H = 0.5 m to 0.8 m.

Figure 3 represents placement of three sensors S1, S2, and S3, which are 0.75 m apart, along with various zone boundaries drawn to the scale. Boundaries of various zones are represented with different colors with the intent to generate appropriate alerts for the driver.

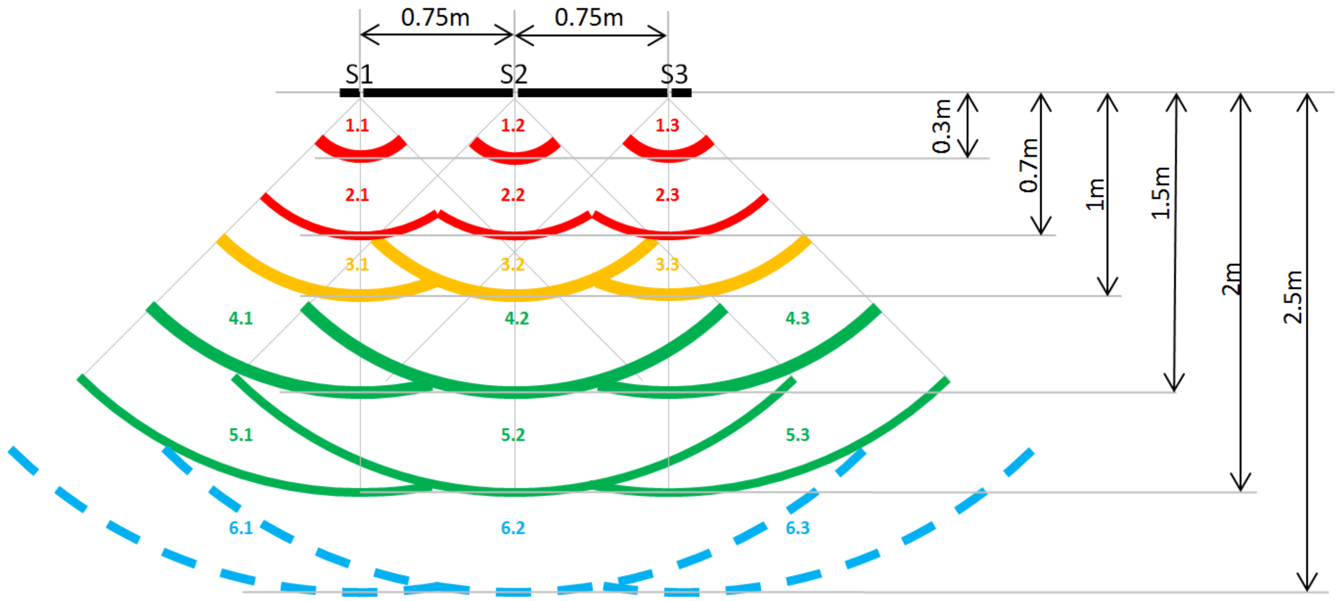

Figure 3. Sensor Placement Diagram

3 Highlighted Product

3.1 PGA460-Q1

This design meets all the requirements previously mentioned using TI's Automotive Ultrasonic Signal Processor and Transducer Driver, PGA460-Q1. The PGA460-Q1 device is a highly-integrated system on-chip ultrasonic transducer driver and signal conditioner with an advanced DSP core. The device has a complimentary low-side driver pair that can drive a transducer either in a transformer-based topology using a step-up transformer or in a direct-drive topology using external high-side FETs. The transformer-driven solution is examined here to meet minimum and maximum range requirement for PAS.

The PGA460-Q1 device can receive and condition the reflected echo signal for reliable object detection. This feature is accomplished using an AFE consisting of a low-noise amplifier followed by a programmable time-varying gain stage feeding into an ADC. The digitized signal is processed in the DSP core for both near-field and far-field object detection using time-varying thresholds.

The main communication with an external controller is achieved by either a time-command interface (TCI) or a one-wire USART asynchronous interface on the IO pin, or a CMOS-level USART interface on the RXD and TXD pins. This system is implemented using a one-wire USART interface to keep the BOM cost and BOM count low.

The PGA460-Q1 device can be put in ultra-low quiescent current low-power mode to reduce power consumption when not in use and can be woken up by commands on the communication interfaces. The PGA460-Q1 device also includes on-chip system diagnostics which monitor transducer voltage during burst, frequency, and decay time of the transducer to provide information about the integrity of the excitation as well as supply-side and transceiver-side diagnostics for overvoltage, undervoltage, overcurrent, and short-circuit scenarios.

4 System Design Theory

A PAS solution can be divided in 3 subsections – Ultra sound sensor (also known as Piezo sensor), sensor driver and receiver circuit (PGA460-Q1), and communication interface for multiple sensors with ECU. This section covers details of each system (or sensor?) here.

4.1 Ultrasound Sensor and Characteristics

PAS controls steering, acceleration, and braking automatically, based on the parking zone and location information gained from the ultrasonic sensor, to achieve parallel parking and garage parking. In the case of the rear sonar, two to four ultrasonic sensors are mounted on the rear bumper to detect an obstacle from 2 to 2.5 m away. The main characteristics of ultrasonic sensors for rear sonar are directivity, ringing time, sensitivity and sound pressure. Directivity of an ultrasonic sensor corresponds to the size and shape of the vibrating surface (that is emitting the ultrasound) and the frequency at which it vibrates.

Consider the MA58MF14-7N device as an example sensor. This device has notches to identify the directivity of the sensor. As Figure 4 shows, the MA58MF14-7N device has a wider view in the horizontal direction than in the vertical direction which means it is an “Asymmetric” ultrasonic sensor. We will be using “Horizontal” placement, which can provide wider coverage with fewer sensors, while narrower vertical directivity improves sensor usability by limiting the effect of reflection from the ground.

4.2 Sensor Circuit Implementation

The transformer-driven configuration uses a center-tap transformer to boost the DC VPWR voltage to a high-voltage sinusoidal driving signal at the secondary. The transformer installed on the daughter card is a fixed-type EPCOS B78416A2232A003. The transformer-driven configuration is typically reserved for closed-top transducers, which require higher driving voltages than open-top transducers. For this reason, the closed-top 58.5-kHz Murata MA58MF14-7N is paired with the transformer. As can be seen in the schematic above (which image?). As Figure 3 shows, overall there are very few components on the sensor PCB and the major space-consuming components are the transformer, 100-µF capacitor (C11), and the PG460-Q1 device.

For automotive applications, the Iso pole is a 75-mm diameter pole which needs to be detected within the entire range from minimum to maximum distance. In this section, register settings and associated device response are illustrated which can be used as a starting point for device configuration. These settings can be further optimized based on algorithm and range requirements.

The PGA460-Q1 EVM GUI was used to optimize the device parameters. There are two threshold sets – Preset 1 (P1) and Preset 2 (P2). P1 is optimized to detect objects in the range of 20 cm to 50 cm with less number of pulses, lower current and shorter record time. P2 is optimized to detect objects in the range of 40 cm to 2.7 m, with a larger number of pulses, higher current, and a longer record time. With the settings shown in Figure 5, the sensor was able to detect an ISO pole in the range as shown in Figure 4.

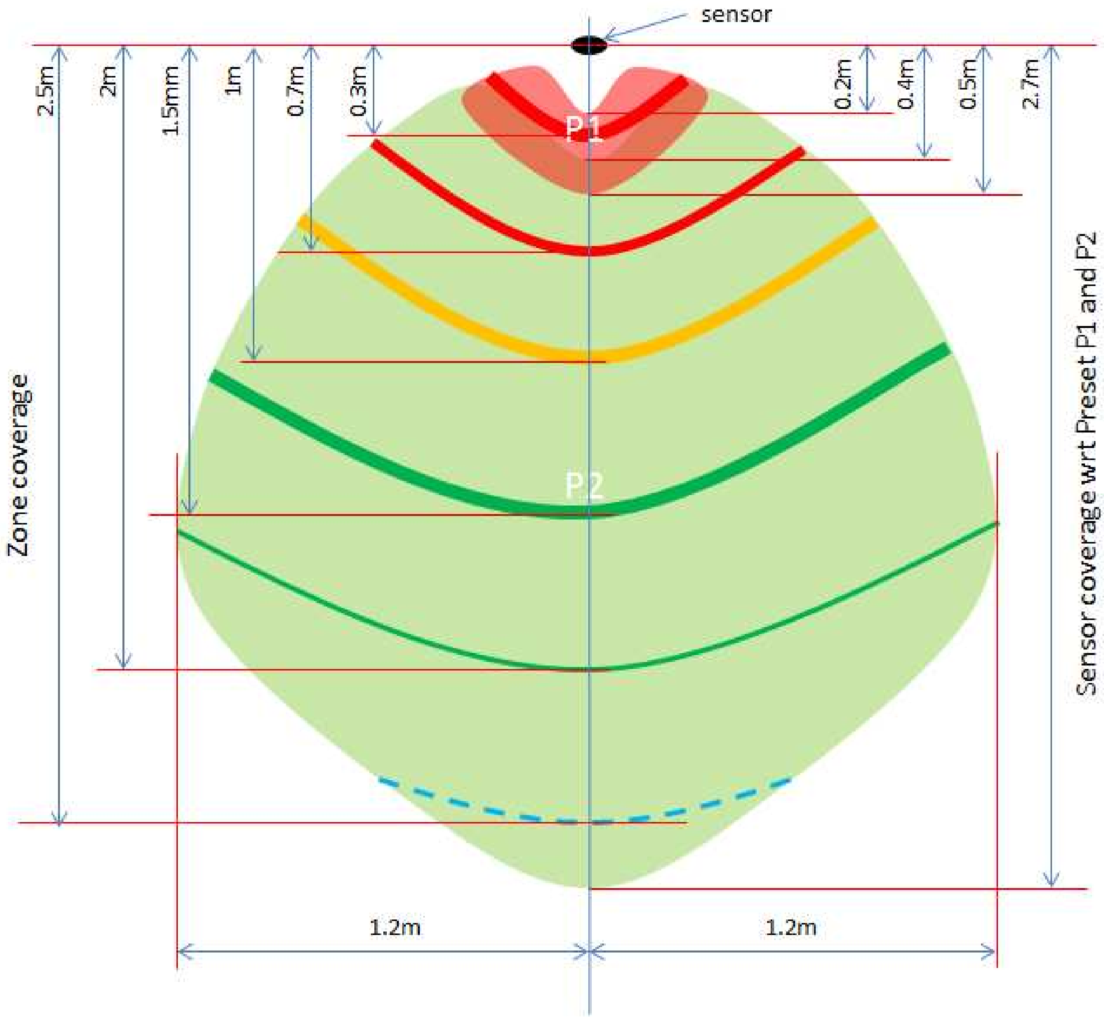

Figure 4. Iso Pole Range

Figure 5 shows a screen shot of the general device settings.

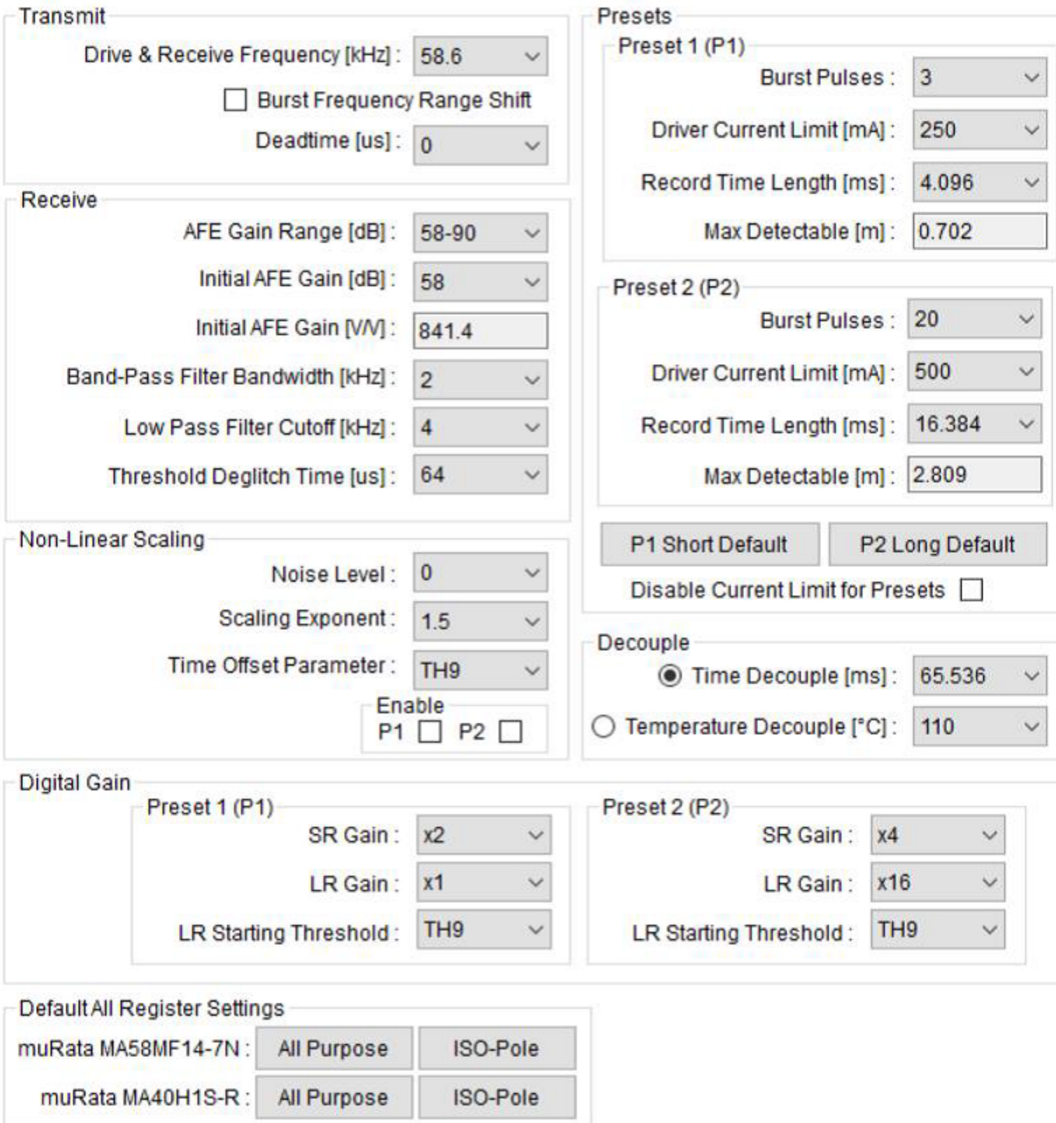

Figure 5. General Device Settings

Figure 6 shows the time-varying gain settings.

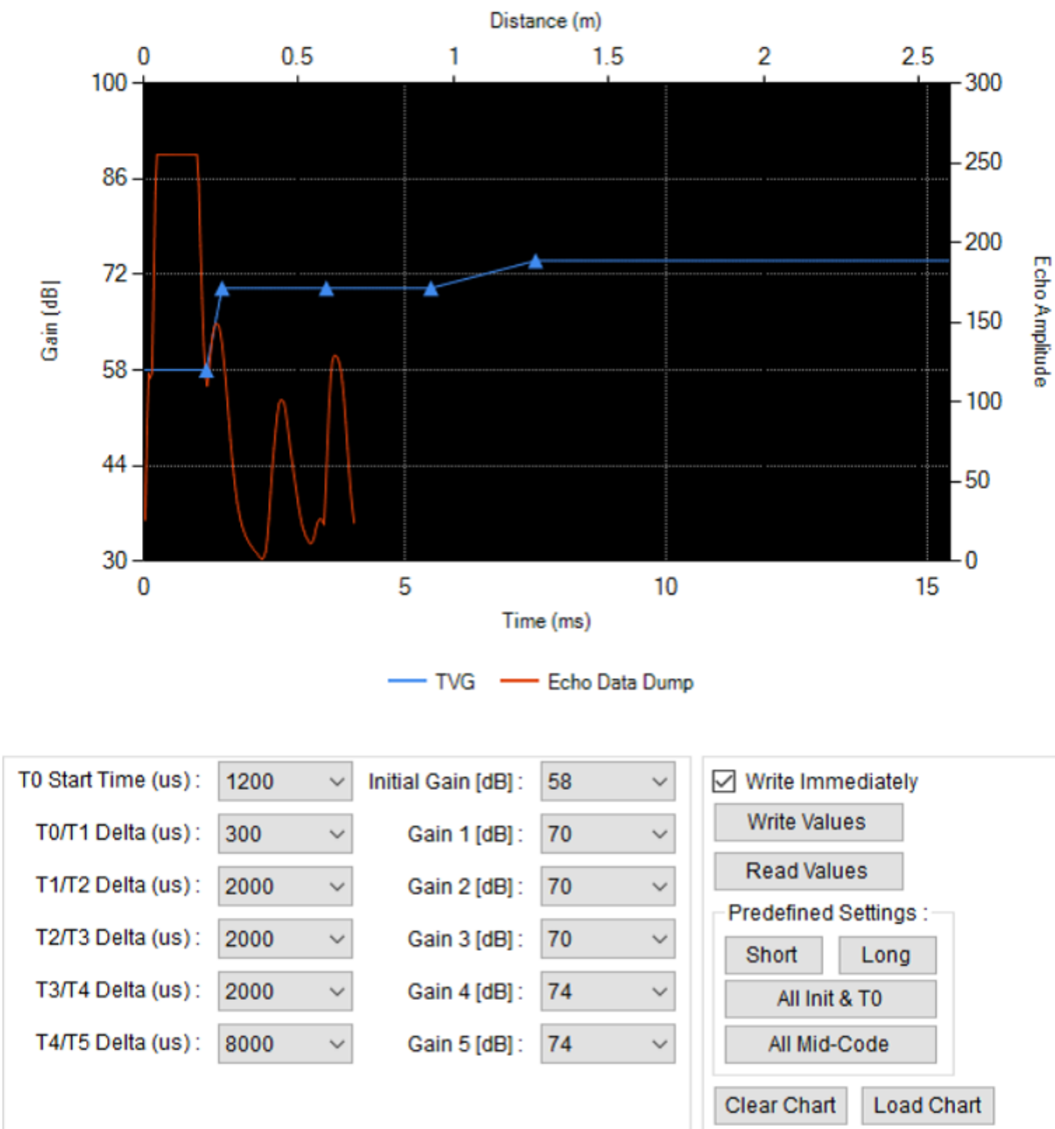

Figure 6. Time-Varying Gain Settings

Figure 7 and Figure 8 show Preset 1 and Preset 2 threshold settings.

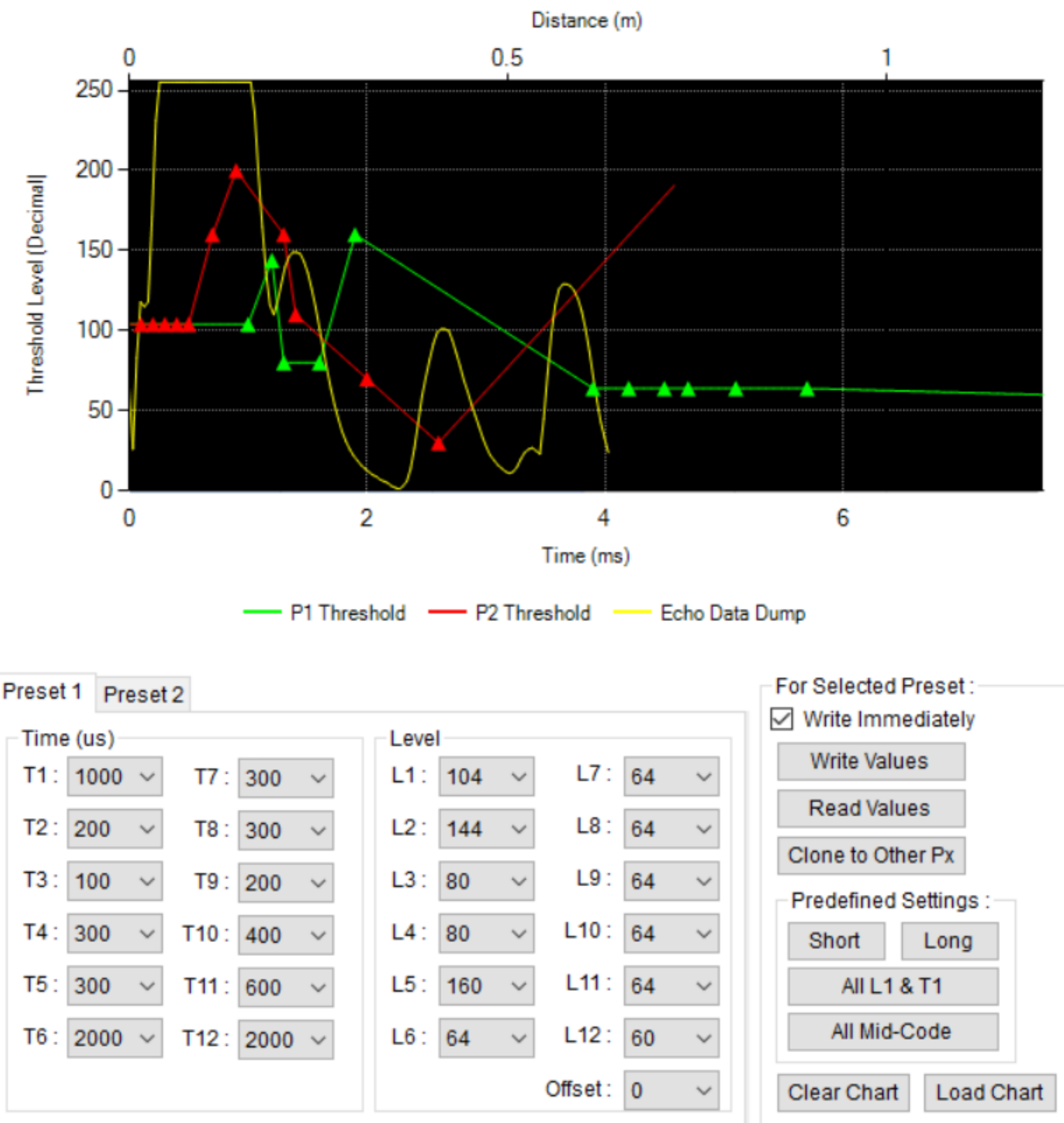

Figure 7. Preset 1 Threshold Settings

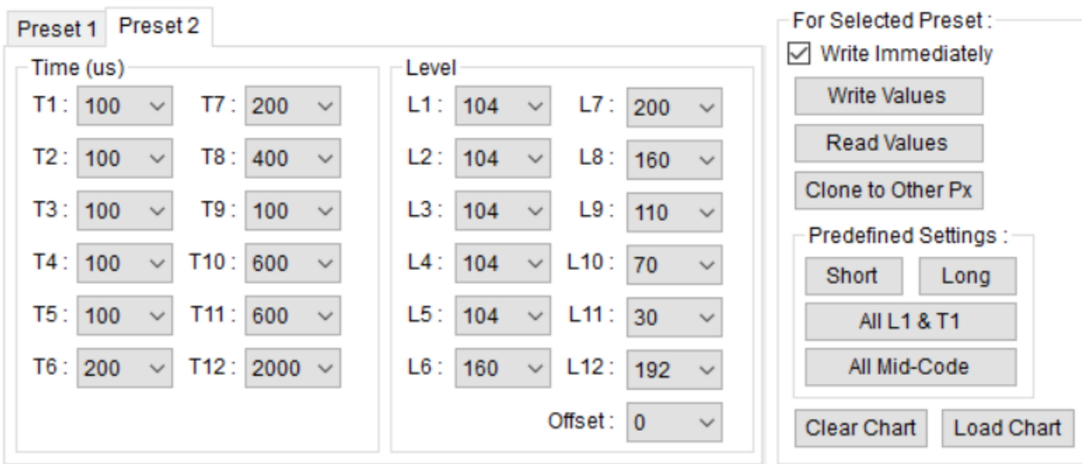

Figure 8. Preset 2 Threshold Settings

Figure 9 illustrates the data monitor screen, demonstrating detection of an object as close as 20 cm from the sensor.

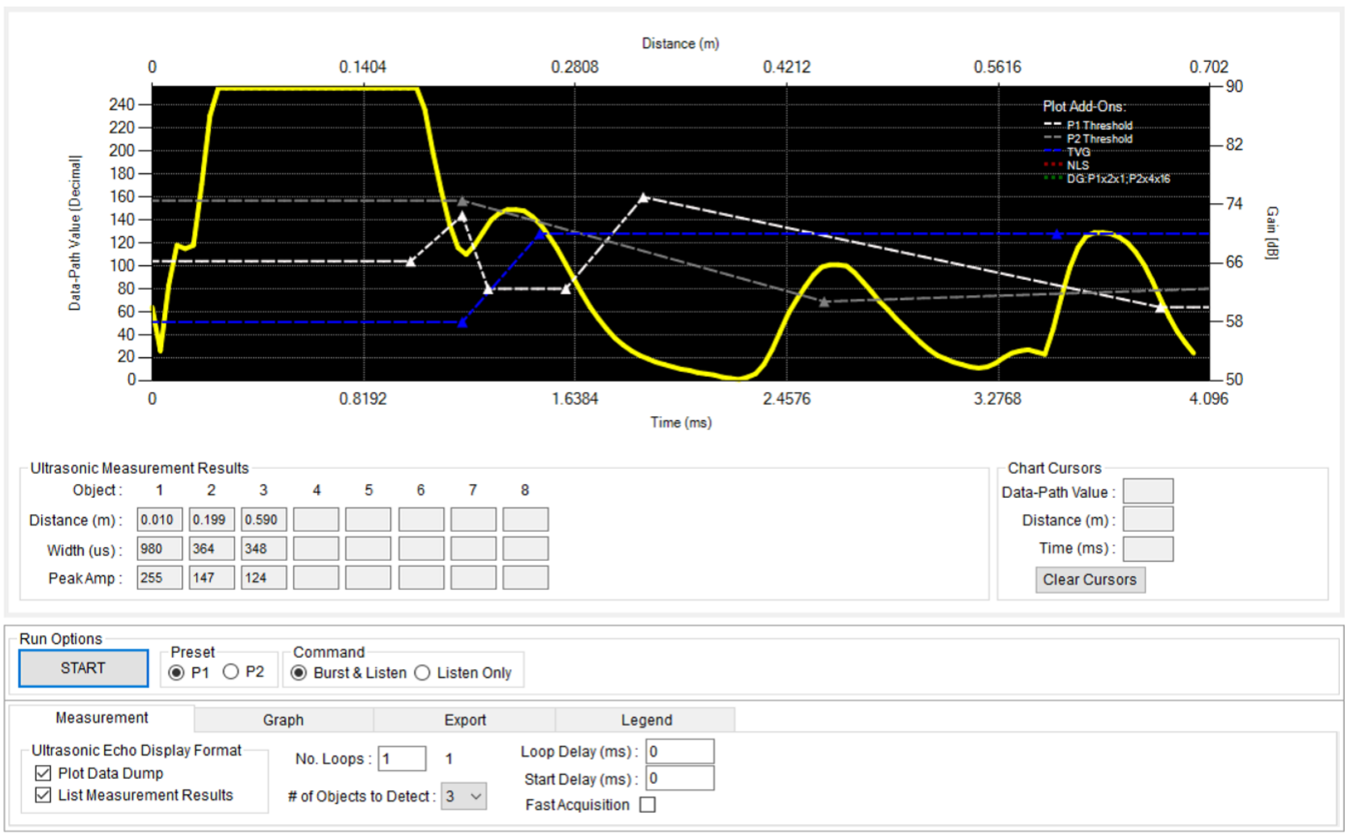

Figure 9. Data Monitor

4.3 System Architecture Options Based on Interface Between Multiple Sensors and ECU

As mentioned in the previous section, the PGA460-Q1 device has the option to communicate with an external controller through multiple interfaces. Though the design is built and tested to use the OWI, we will briefly go over the other interface options, along with associated system level requirements to explain the motivation behind using the OWI.

The PGA460-Q1 device is equipped with two communication interfaces, each with designated pins. The TCI is connected to the IO pin which is an open-drain output structure with an internal 10-kΩ pullup resistor capable of communicating at battery level voltage. The asynchronous UART interface can communicate on the IO pin, and is also connected to the RXD and TXD pins. A third Interface option is to use the synchronous USART interface which is available only at the RXD and TXD pins. This communication uses SCLK pin for a serial clock input and is the fastest data-rate mode. USART communication on RXD and TXD pins is available at a 3.3-V or 5-V CMOS level, depending on the configured IOREG voltage.

For more details on each interface and how to configure the PGA460-Q1 for each interface, see *PGA460-Q1 Automotive Ultrasonic Signal Processor and Transducer Driver*..

4.3.1 CMOS-Level USART Synchronous Interface (Through PGA460-Q1 RXD and TXD Pins)

The USART Synchronous interface allows easy access to all the registers, EEPROM and the device address. As mentioned above, this mode uses and is only available on the RXD and TXD pins, but also uses the SCLK pin as a clock input for communication to the device. Systems with a local MCU close to PGA460-Q1 can utilize this interface for faster communication. After programming different addresses to multiple PGA460-Q1 devices, maximum 8 devices can be connected on a single USART bus. (-disconnect-) However for PAS, it is not cost effective to have a local MCU for each sensor. Also, it is not possible to use USART over very long wires from individual sensors to an MCU.

4.3.2 Time-Command Interface (TCI, Through the PGA460-Q1 IO Pin)

While using the Time-Command Interface, the PGA460-Q1 device will receive a simple time-based command from an MCU to execute various functions using the IO Pin. This interface does not use any addressing. Hence, it is not possible to connect multiple PGA460-Q1 devices on a single TCI bus in most PAS systems, where information from the individual sensor is separated. Because this interface utilizes the PGA460-Q1 IO pin and communicates using high voltage (the same as VPWR of the PGA460-Q1 device), it cannot be connected directly to a 3.3-V or 5-V MCU. Therefore, while communicating through the IO line, a level translator circuit shown in Figure 10 is necessary before the MCU.

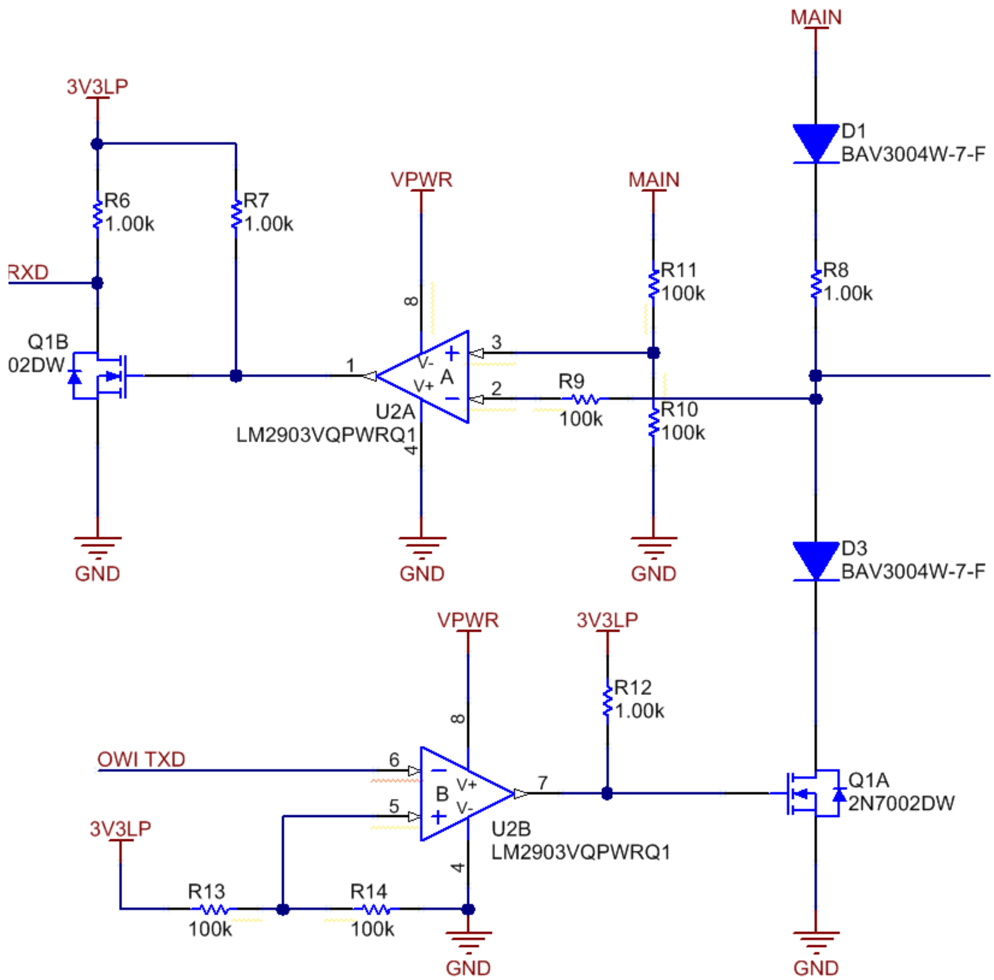

Figure 10. TCI Level Translator Schematic

Use the SN65HVDA100-Q1 device for the same functionality as shown in <add xref> (which section? - TP). This block is called the "OWI transceiver" for remaining topics. Figure 11 illustrates the architecture of the system with the TCI.:

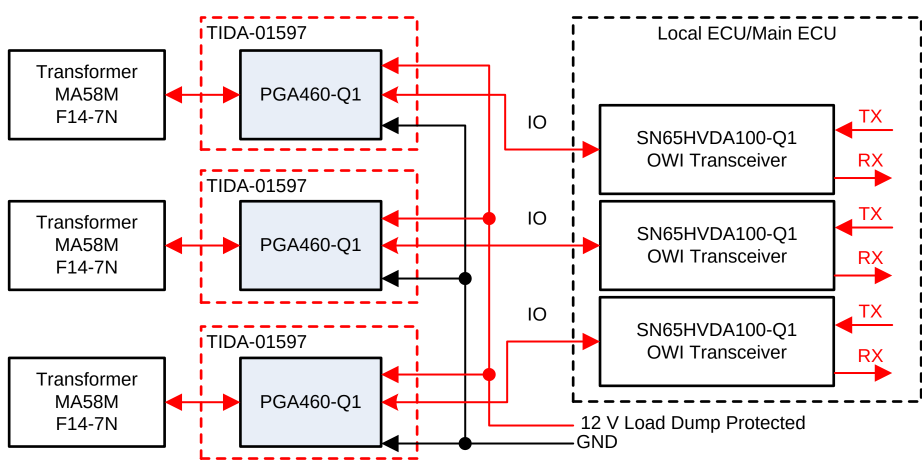

Figure 11. TCI System Architecture

The PGA460-Q1 device is factory programmed with TCI enabled on the IO pin. For details on how to change the interface from TCI to OWI, see the in-system IO-pin interface selection section of the *PGA460-Q1 Automotive Ultrasonic Signal Processor and Transducer Driver Data Sheet*.

4.3.3 One-Wire USART Asynchronous Interface (Through PGA460-Q1 IO Pin

This interface also utilizes the IO line on the PGA460-Q1 device. Because of addressing, while using this interface, up to 8 sensors can be connected on the same bus, which has an advantage over the TCI. Figure 12 shows how only a single OWI transceiver block can be used while communicating with multiple sensors.

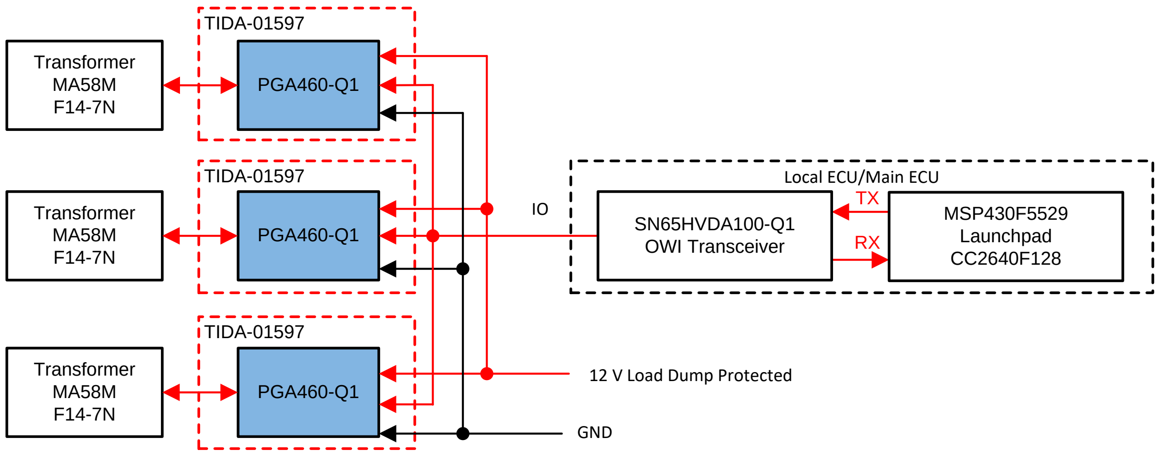

Figure 12. OWI System Architecture

This approach significantly reduces BOM cost and BOM count of the system as compared to conventional methods. It also simplifies the wiring harness and installation by allowing communication of multiple sensors over a single wire.

Figure 13 shows circuit implementation of the OWI transceiver using the SN65HVDA100-Q1 device to communicate with the 3.3-V MCU. The same circuit can be used with the 5-V MCU. Use pin 7, 8, 9, and 10 of J10 to communicate with multiple sensors through a common line.

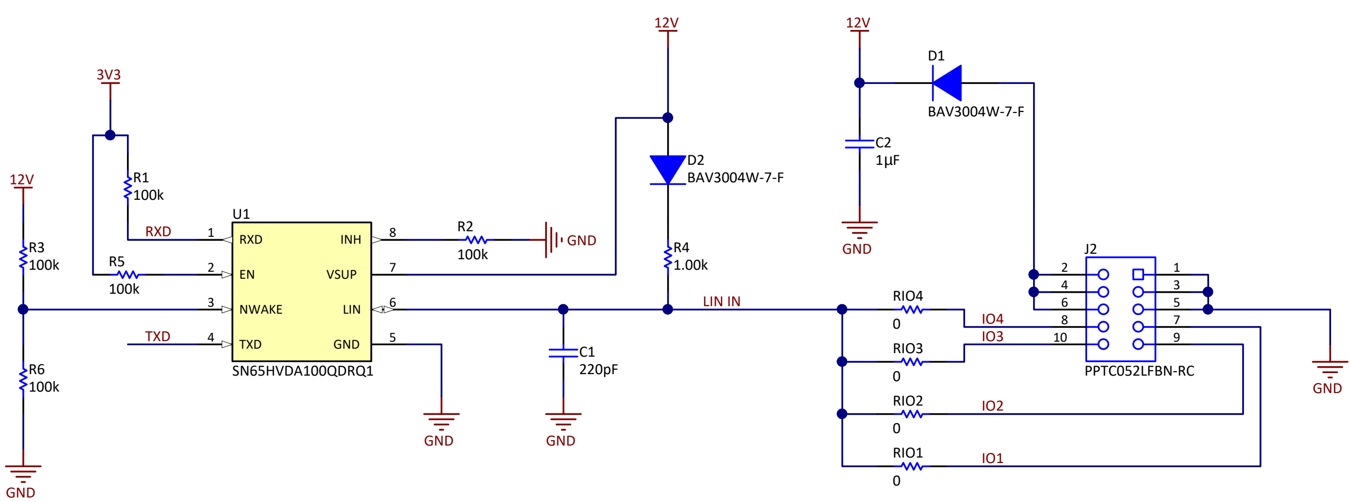

Figure 13. OWI Transceiver Schematic

Note that for the OWI transceiver section and the sensor section, the necessary protection circuit must be included on the IO line, such as the TVS diode or C-L-C filter in accordance with EMI, EMC tests to be passed and to make sure that the voltage level on the device pins does not exceed the rated value in the device data sheet.

5 Hardware, Software, Testing, and Test Results

5.1 Required Hardware and Software

5.1.1 Hardware

Figure 14 shows the TIDA-01597 system hardware.

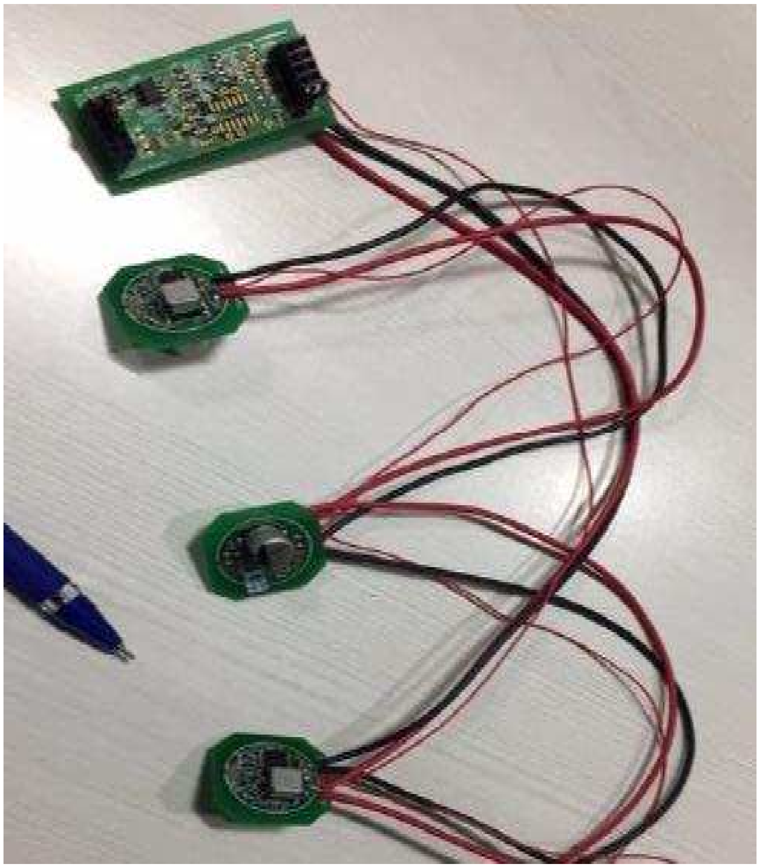

Figure 14. TIDA-01597 System Hardware - Three Sensor Transducer Boards and an OWI Transceiver

5.1.2 Programming the PGA460-Q1

Configure the TIDA-01597 using the following steps:

1. Assemble the 3-sensor PCBs – S1, S2, and S3 with the corresponding Piezo sensors.
2. Connect a 12-V supply, GND, and CMOS-USART connection to S1.
3. Access CMOS-USART to change the sensor address and to change the communication interface over the IO pin to one-wire USART. (Use an unique address for S1, S2, and S3; for example 001, 010, and 011, respectively)
4. Optional step – EEPROM registers of the PGA460-Q1 device can be programmed using CMOS-USART (which is faster) or programmed later in the system through one-wire USART.
5. Repeat steps 2, 3, and 4 for S2 and S3.
6. Assemble the complete system with all the sensors connected to a common IO line, 12-V supply, and GND.
7. Complete the remaining device configuration after every power cycle by accessing individual sensors through their unique addresses.
8. Now individual sensors are accessed and commanded to execute functions as implemented in the algorithm.

Table 2 lists the register names, addresses, and values to configure the TIDA-01597.

Table 2. Register Initialization

EEPROM REGISTER	REGISTER ADDRESS	Default Value
USER_DATA1-USER_DATA-20	0h-13h	00h
TVGAIN0	14	AFh
TVGAIN1	15	FFh
TVGAIN2	16	FFh
TVGAIN3	17	2Dh
TVGAIN4	18	68h
TVGAIN5	19	36h
TVGAIN6	1A	FCh
INIT_GAIN	1B	C0h
FREQUENCY	1C	8Ch
DEADTIME	1D	00h
PULSE_P1	1E	01h
PULSE_P2	1F	12h
CURR_LIM_P1	20	47h
CURR_LIM_P2	21	FFh
REC_LENGTH	22	1Ch
FREQ_DIAG	23	00h
SAT_FDIAG_TH	24	EEh
FVOLT_DEC	25	7Ch
DECPL_TEMP	26	0Ah
TEMP_TRIM	27	00h
P1_GAIN_CTRL	28	00h
P2_GAIN_CTRL	29	00h
EE_CRC	2A	Auto calculated on EEPROM burn

It is possible to update the IO_IF_SEL bit from the default value of ‘0’ (for TCI mode) to ‘1’ (for OWU mode) without needing to connect the PGA460 UART pins to a master. The procedure is as follows for a factory device:

1. Power on the device. By factory default, the device is ready for UART and IO-TCI mode.
2. To toggle from TCI to OWU mode, send the in-system IO pin toggle pattern as described in the in-system IO-pin interface selection section of the *PGA460-Q1 Automotive Ultrasonic Signal Processor and Transducer Driver Data Sheet*.

NOTE: As soon as the toggle pattern is received by the PGA460, the interface on the IO-pin is toggled. The pattern in the IO-pin interface toggle pattern image in the data sheet toggles the value of the IO_IF_SEL bit; however, it does not program the EEPROM.

3. The device is now ready for UART and IO-OWU mode commands.
4. As soon as the PGA460 IO interface is set to the target interface (OWU mode), the master controller must issue a command to program the EEPROM with the desired configuration. The device can be EEPROM programmed via OWU mode (the same EEPROM programming write procedure as described in the device data sheet as UART) to save the IO selection upon power-cycle or start-up for OWU mode.

NOTE: UART_ADDR can also be updated and programmed in OWU mode.

5.2 Test Setup

Figure 15 shows the object placement in the test setup.

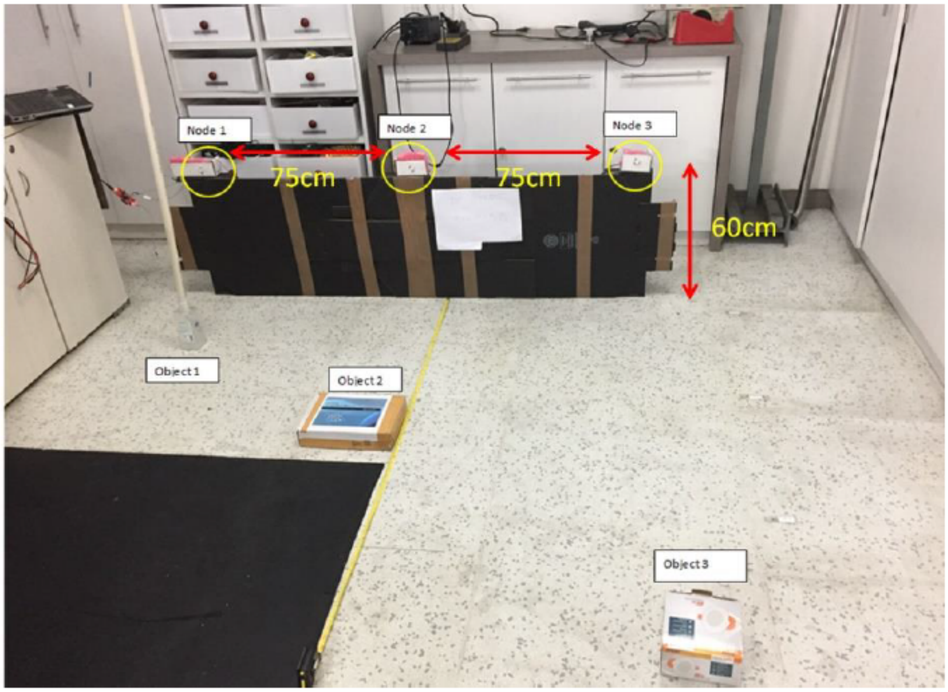

Figure 15. Test Setup - Object Placement

5.3 Test Results

Figure 16 and Figure 17 show the output over UART and OWUI, respectively.

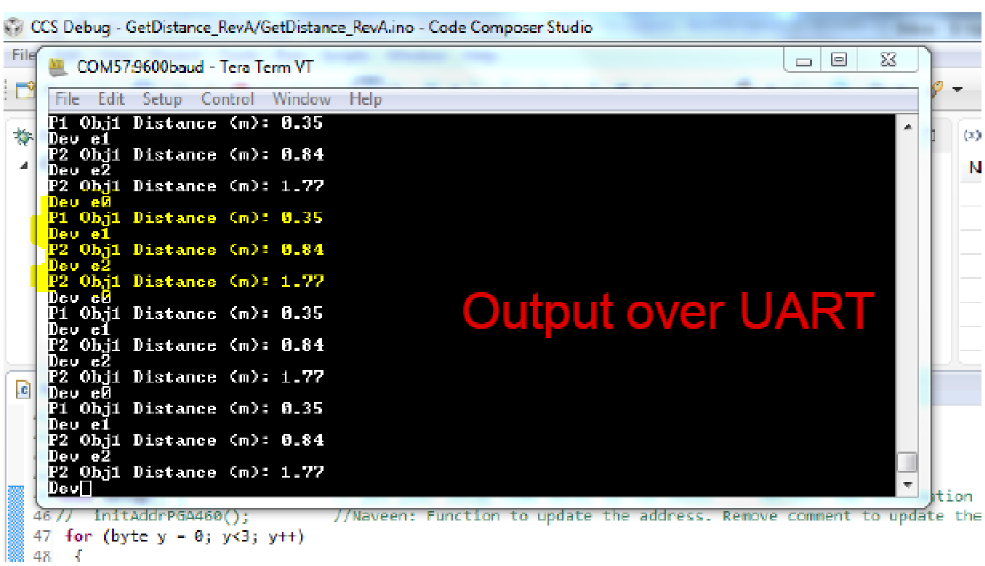

Figure 16. Output Over UART

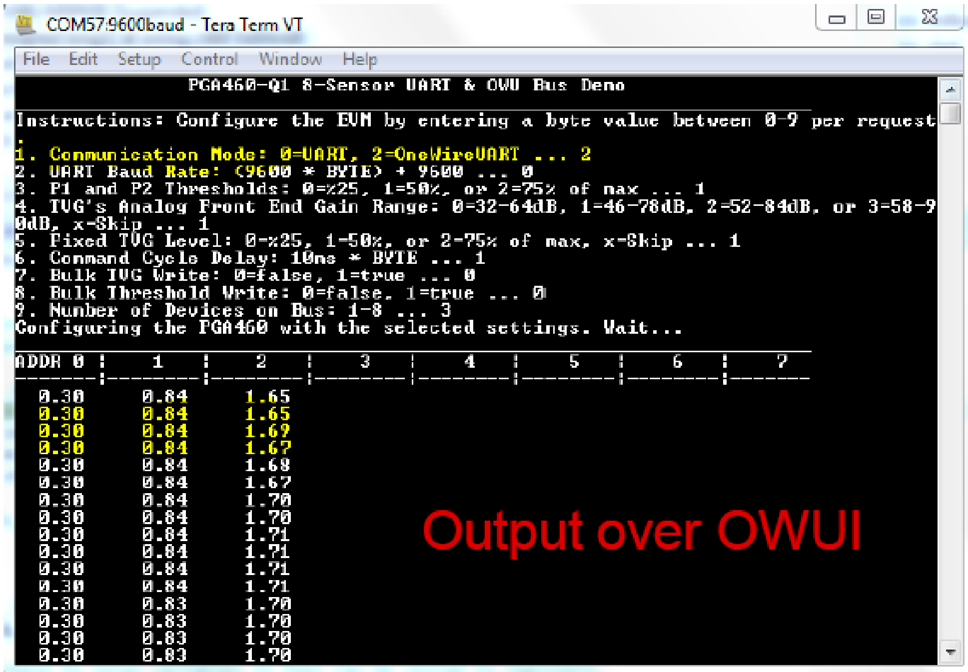

Figure 17. Output Over OWUI

6 Design Files

6.1 Schematics

To download the schematics, see the design files at TIDA-01597.

6.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01597.

6.3 PCB Layout

6.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01597.

6.4 Altium Project

To download the Altium project files, see the design files at TIDA-01597.

6.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01597.

6.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01597.

7 Software Files

To download the software files, see the design files at TIDA-01597.

8 Related Documentation

1. *PGA460-Q1 Automotive Ultrasonic Signal Processor and Transducer Driver Data Sheet*

8.1 Trademarks

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