

TI Designs: TIDA-01597

适用于停车辅助的汽车超声波传感模块参考设计



说明

该参考设计利用三块高度集成的片上系统 (SoC) 超声波传感器驱动器为停车辅助系统 (PAS) 提供硬件架构。这些超声波传感器驱动器带有集成信号调节器, 配备高级数字信号处理器 (DSP) 内核。使用这些集成特性, 可实现对 25cm 至 2.5m 范围内物体的检测。距离数据将通过一个单线接口 (OWI) 发送至本地电子控制单元 (ECU), 并在此进行聚合与处理。此设计指南所介绍的传感器初始化、物体检测算法以及软件为开发汽车或防撞 PAS 的工程师提供了一个基础的框架。

资源

[TIDA-01597](#) 设计文件夹
[PGA460-Q1](#) 产品文件夹

特性

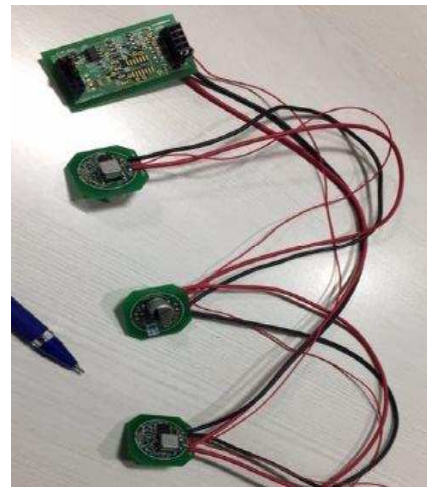
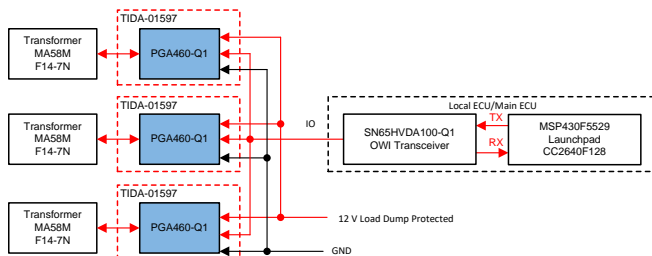
- 整合了三个 PGA460-Q1 器件, 可检测 25cm 至 2.5m 范围内的物体
- 提供系统诊断信息
- 包含电平 USART 和 TCI 接口选项的电路
- 解决方案尺寸 (直径) 为 22mm

应用

- 超声波停车辅助
- 碰撞避免



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该 TI 参考设计末尾的重要声明表述了授权使用、知识产权问题和其他重要的免责声明和信息。

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

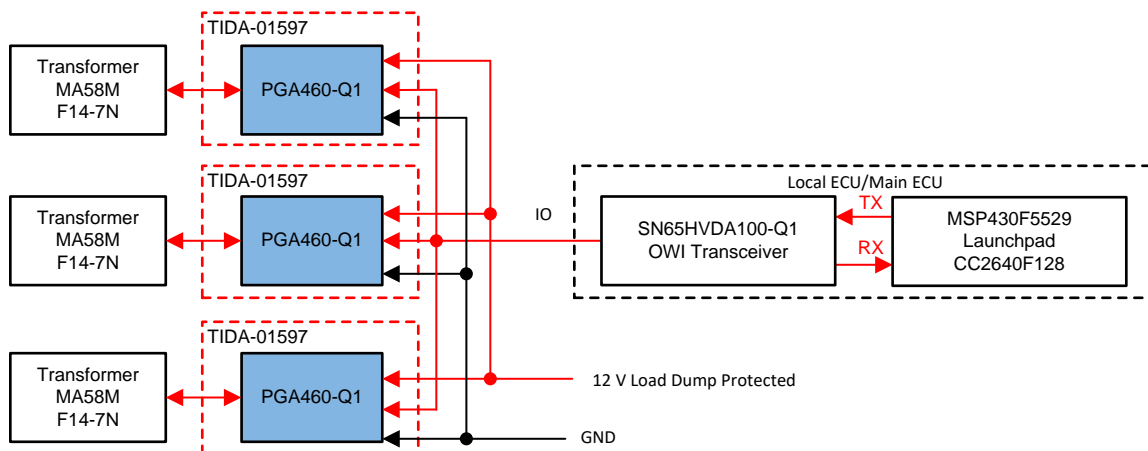


图 1. TIDA-01597 Block Diagram

2.2 Design Considerations

表 1 和 图 2 显示了一辆汽车的平均尺寸。一辆平均汽车的宽度在 1.5 m 到 1.75 m 之间。如前所述，为了在倒车过程中检测到汽车后方的物体，泊车辅助解决方案应覆盖整个后侧和盲区。

表 1. Example Dimensions of Car

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

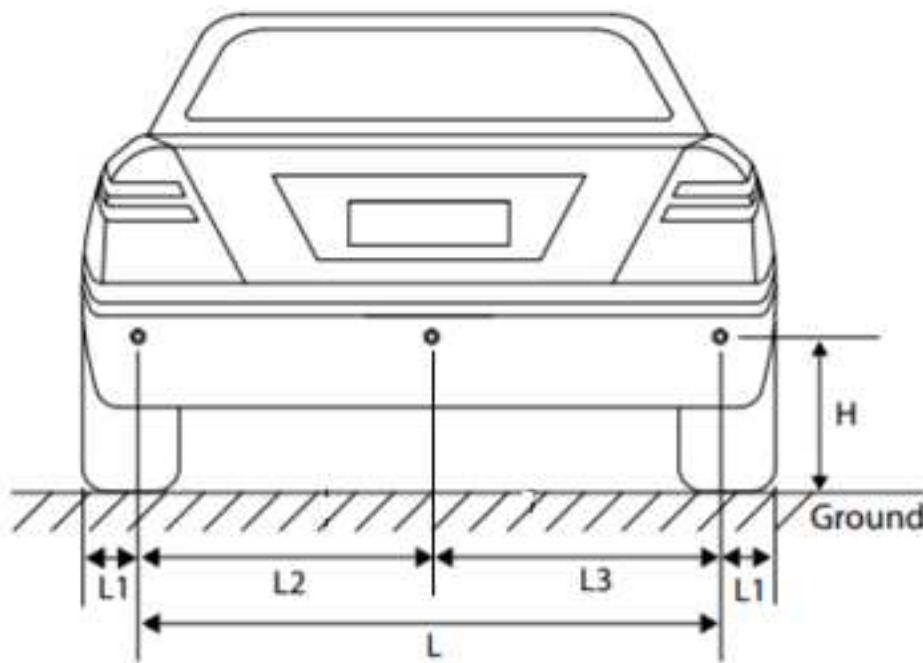


图 2. Car Dimensions

作为一个实际系统的例子，考虑一辆宽度为 1.7 m 的汽车。参照图 2， $L1 + L2 + L3 + L1 = 1.7$ m。如果 $L1 = 0.1$ m，那么相邻传感器之间的距离， $L2 = L3 = 0.75$ m 且传感器的近似高度为 $H = 0.5$ m 到 0.8 m。

图 3 表示三个传感器 S1、S2 和 S3 的放置，它们相距 0.75 m，以及绘有比例尺的各色区域边界。各色区域边界是为了生成适当的驾驶员警报而绘制的。

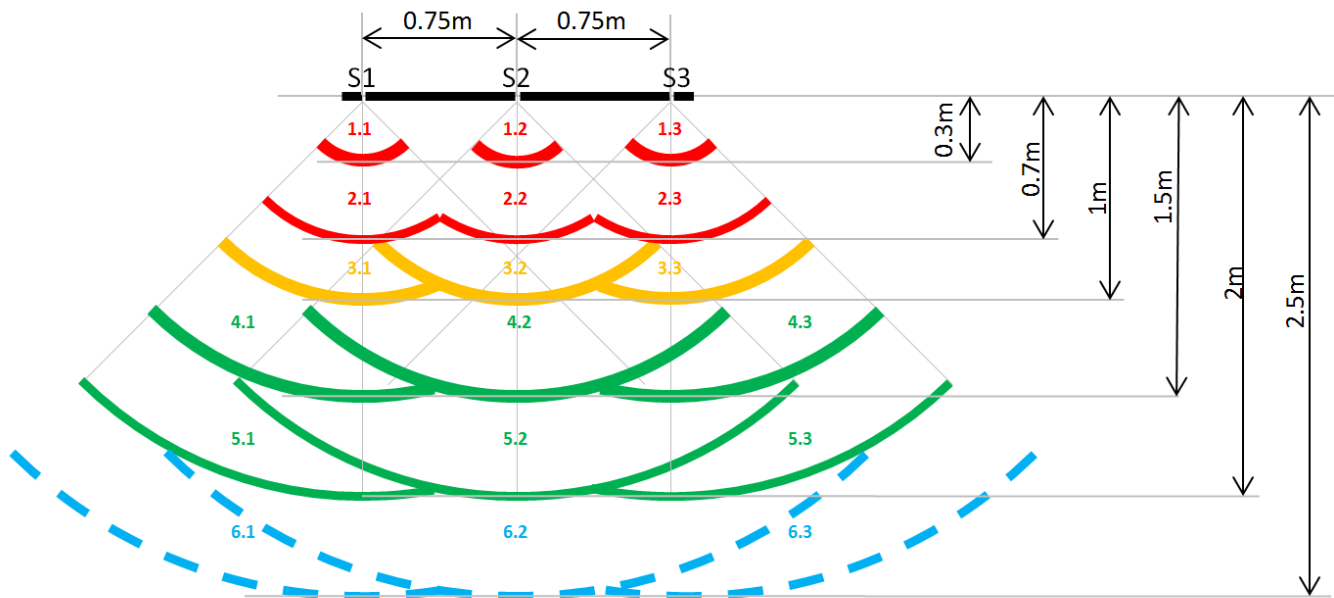


图 3. Sensor Placement Diagram

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 [图 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 [图 3](#) shows, overall there are very few components on the sensor PCB and the major space-consuming components are the transformer, 100- μ F 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 [图 5](#), the sensor was able to detect an ISO pole in the range as shown in [图 4](#).

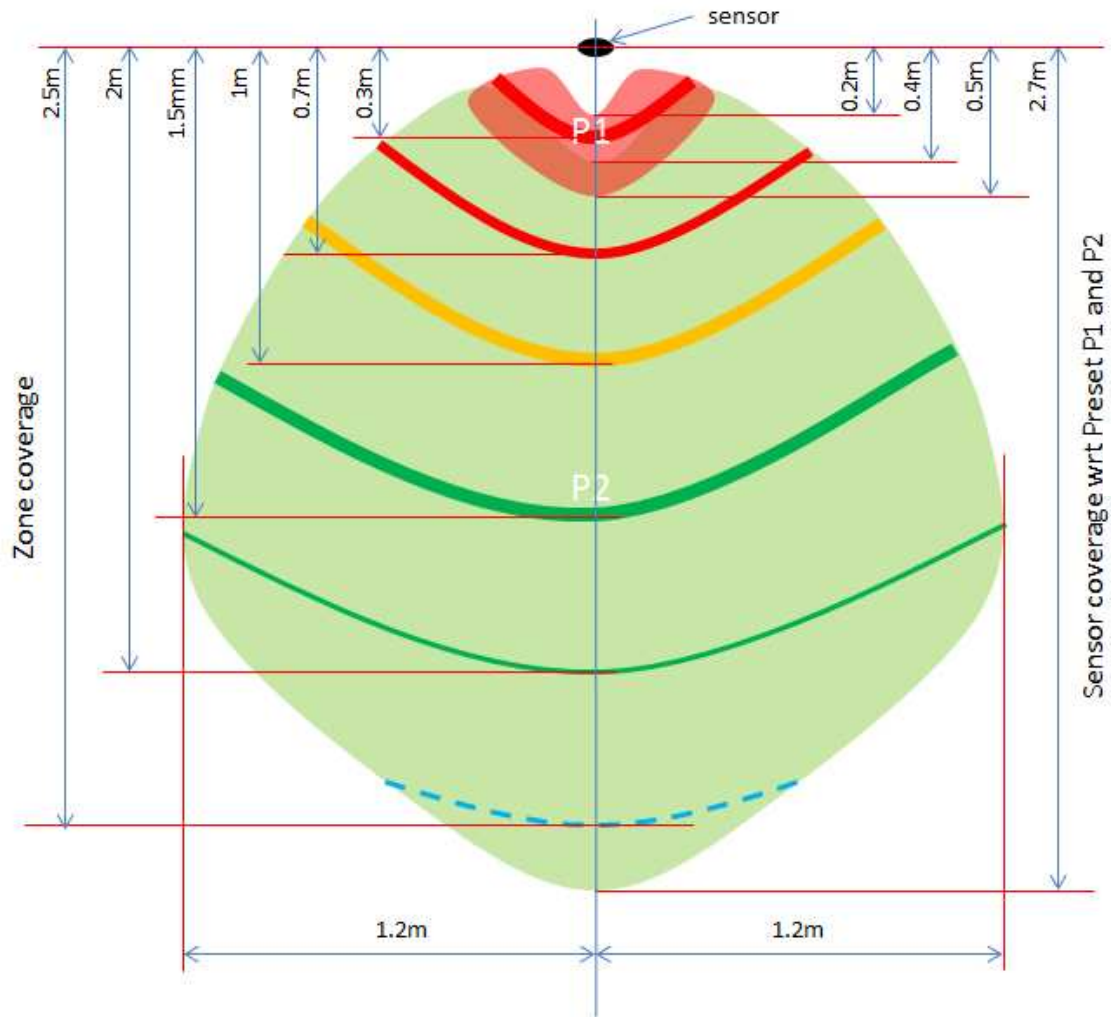


图 4. Iso Pole Range

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

The screenshot displays the 'General Device Settings' interface, organized into several sections:

- Transmit:** Drive & Receive Frequency [kHz]: 58.6; Burst Frequency Range Shift; Deadtime [us]: 0.
- Receive:** AFE Gain Range [dB]: 58-90; Initial AFE Gain [dB]: 58; Initial AFE Gain [V/V]: 841.4; Band-Pass Filter Bandwidth [kHz]: 2; Low Pass Filter Cutoff [kHz]: 4; Threshold Deglitch Time [us]: 64.
- Non-Linear Scaling:** Noise Level: 0; Scaling Exponent: 1.5; Time Offset Parameter: TH9; Enable P1 P2 .
- Digital Gain:** Preset 1 (P1) SR Gain: x2, LR Gain: x1, LR Starting Threshold: TH9; Preset 2 (P2) SR Gain: x4, LR Gain: x16, LR Starting Threshold: TH9.
- Presets:** Preset 1 (P1) Burst Pulses: 3, Driver Current Limit [mA]: 250, Record Time Length [ms]: 4.096, Max Detectable [m]: 0.702; Preset 2 (P2) Burst Pulses: 20, Driver Current Limit [mA]: 500, Record Time Length [ms]: 16.384, Max Detectable [m]: 2.809. Includes buttons for 'P1 Short Default' and 'P2 Long Default', and a checkbox for 'Disable Current Limit for Presets'.
- Decouple:** Time Decouple [ms]: 65.536; Temperature Decouple [°C]: 110.
- Default All Register Settings:** muRata MA58MF14-7N: All Purpose, ISO-Pole; muRata MA40H1S-R: All Purpose, ISO-Pole.

图 5. General Device Settings

图 6 shows the time-varying gain settings.

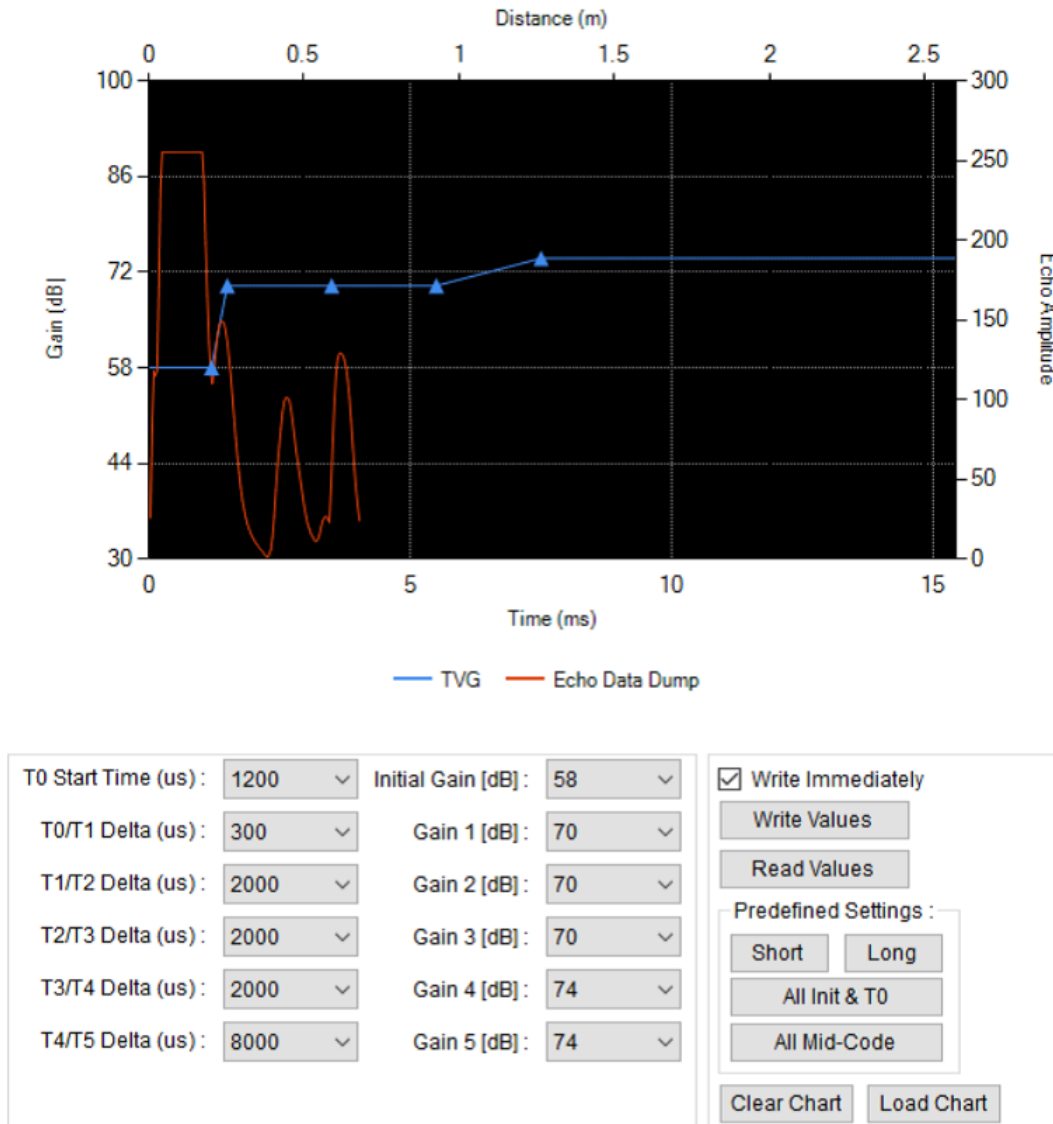


图 6. Time-Varying Gain Settings

图 7 和 图 8 显示 Preset 1 和 Preset 2 阈值设置。

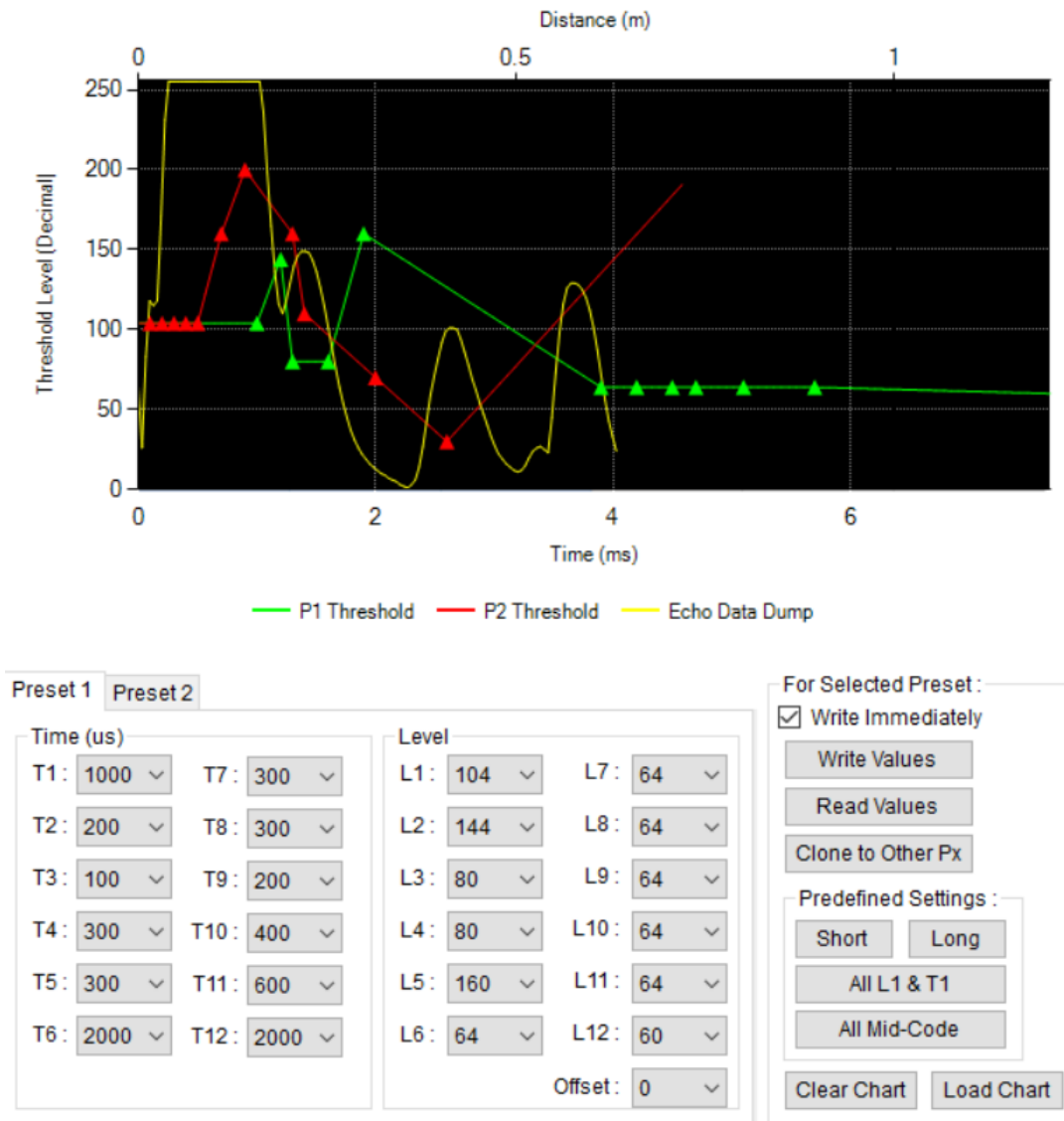


图 7. Preset 1 Threshold Settings

Preset 1 **Preset 2**

Time (us)

T1: 100 ▼ T7: 200 ▼

T2: 100 ▼ T8: 400 ▼

T3: 100 ▼ T9: 100 ▼

T4: 100 ▼ T10: 600 ▼

T5: 100 ▼ T11: 600 ▼

T6: 200 ▼ T12: 2000 ▼

Level

L1: 104 ▼ L7: 200 ▼

L2: 104 ▼ L8: 160 ▼

L3: 104 ▼ L9: 110 ▼

L4: 104 ▼ L10: 70 ▼

L5: 104 ▼ L11: 30 ▼

L6: 160 ▼ L12: 192 ▼

Offset: 0 ▼

For Selected Preset:

Write Immediately

Write Values

Read Values

Clone to Other Px

Predefined Settings:

Short Long

All L1 & T1

All Mid-Code

Clear Chart Load Chart

图 8. Preset 2 Threshold Settings

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

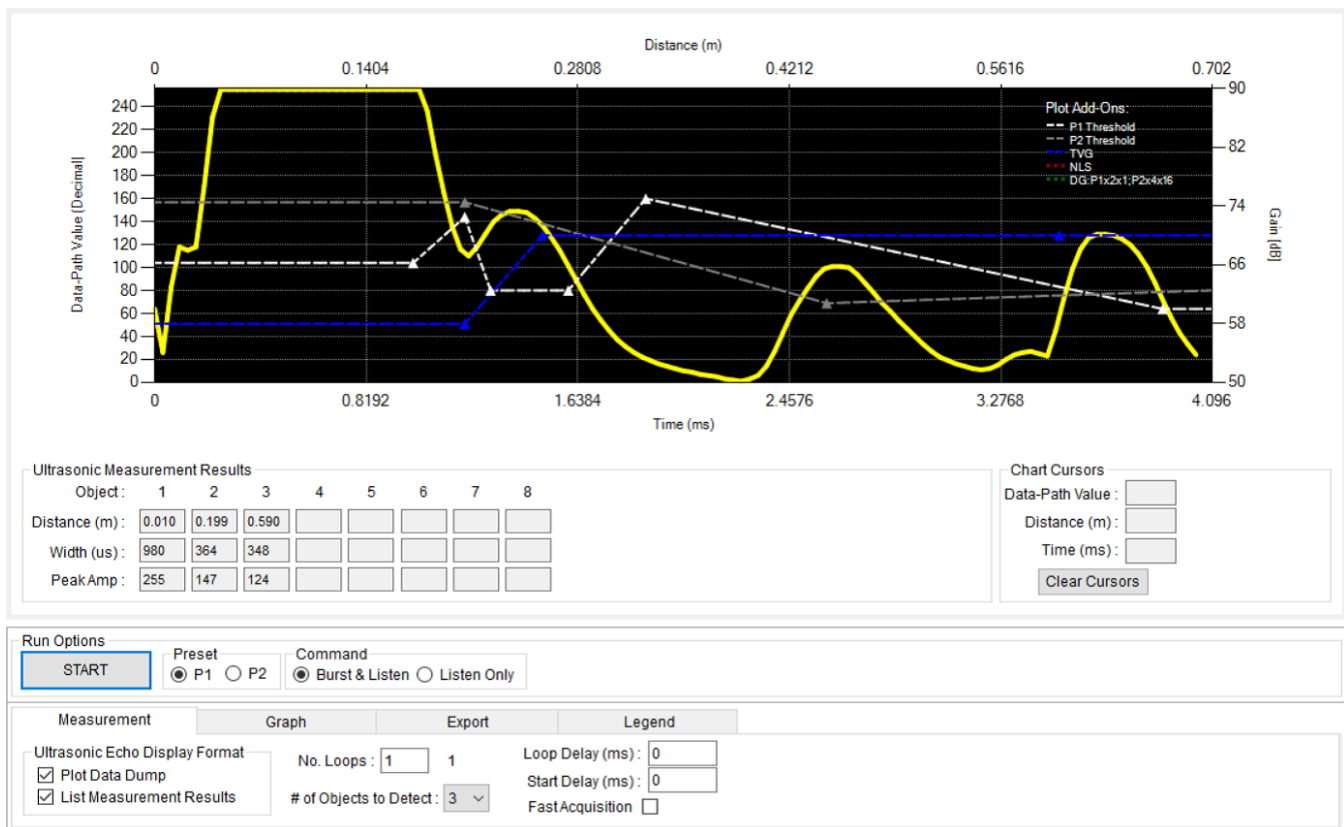


图 9. Data Monitor

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-k Ω 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 [图 10](#) is necessary before the MCU.

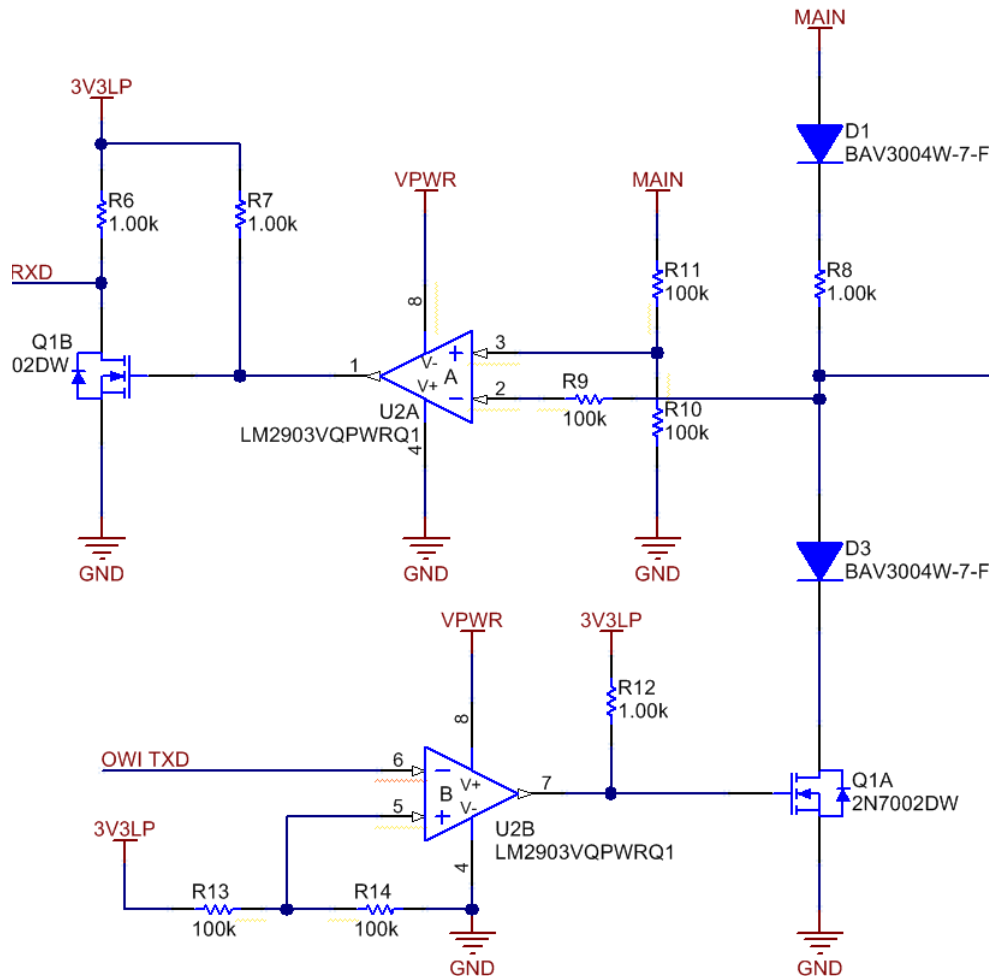


图 10. TCI Level Translator Schematic

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. 图 11 illustrates the architecture of the system with the TCI.:

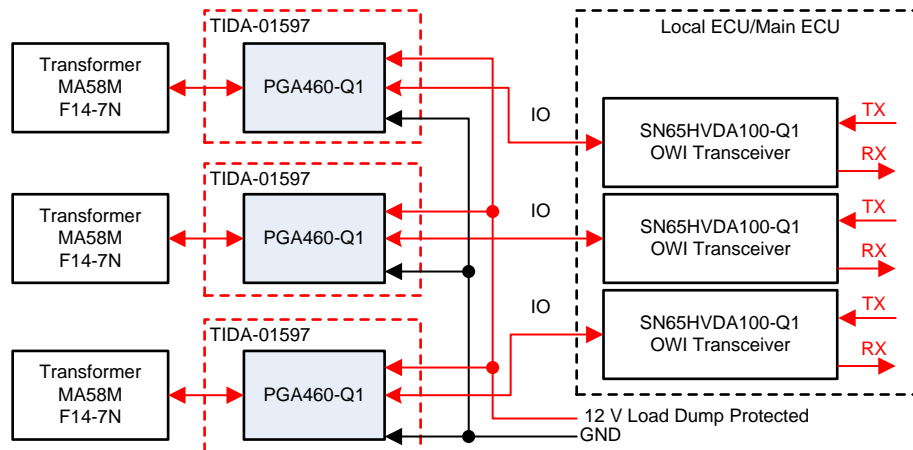


图 11. TCI System Architecture

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. [图 12](#) shows how only a single OWI transceiver block can be used while communicating with multiple sensors.

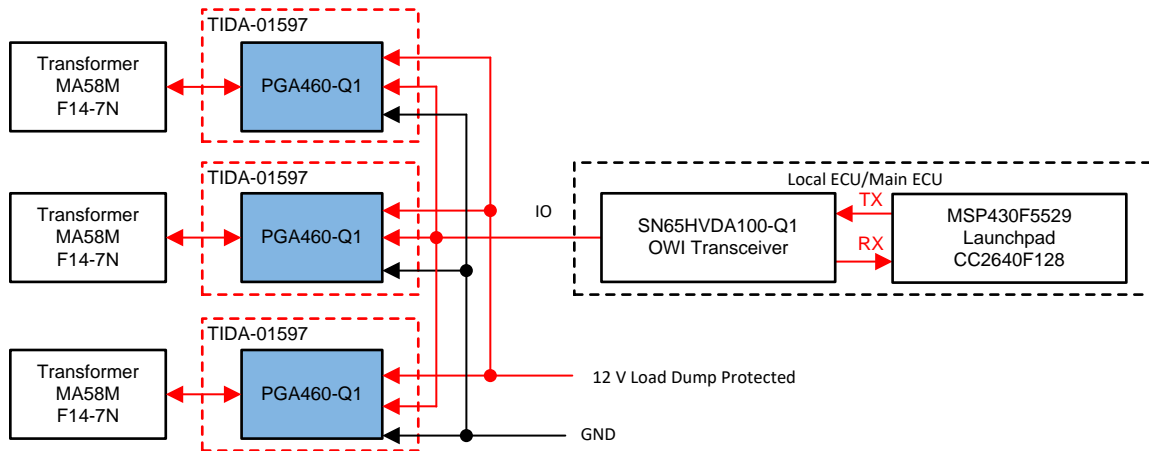


图 12. OWI System Architecture

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.

[图 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.

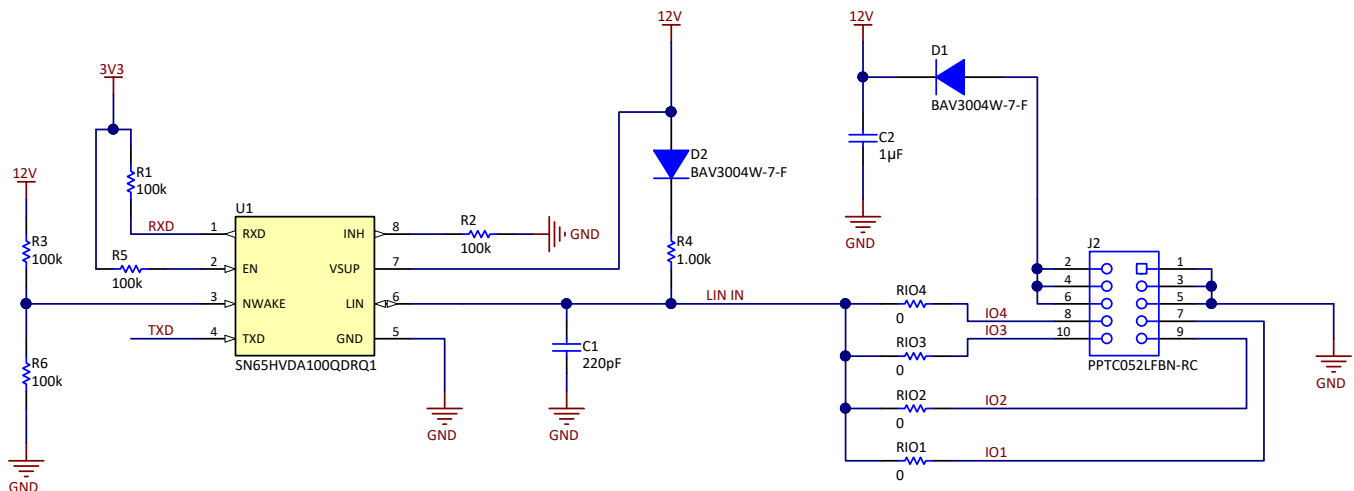


图 13. OWI Transceiver Schematic

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

图 14 shows the TIDA-01597 system hardware.

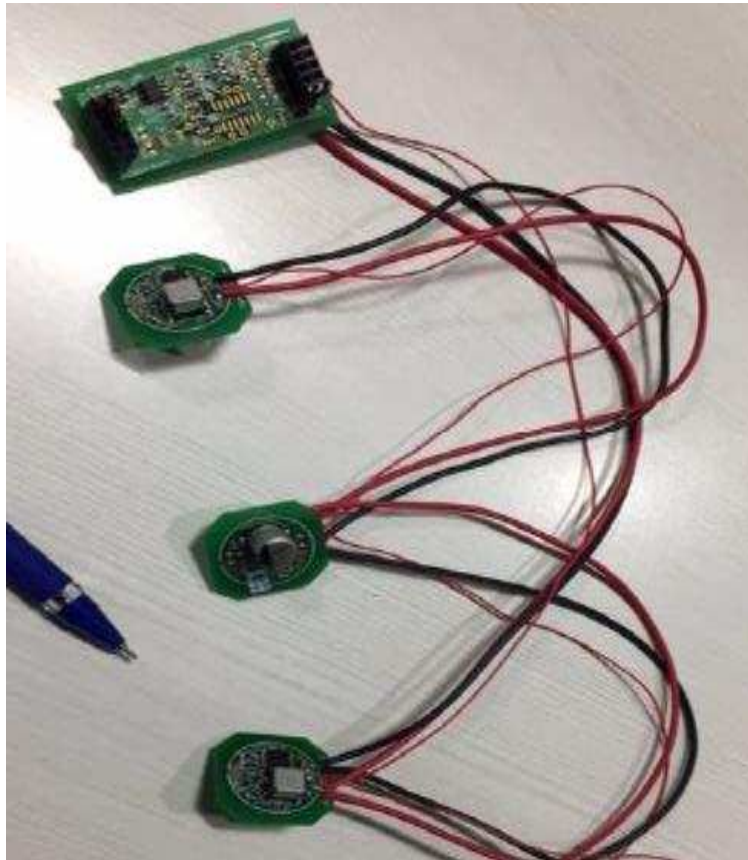


图 14. TIDA-01597 System Hardware - Three Sensor Transducer Boards and an OWI Transceiver

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 a 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.

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

表 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](#).

注: 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.

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

5.2 Test Setup

图 15 shows the object placement in the test setup.

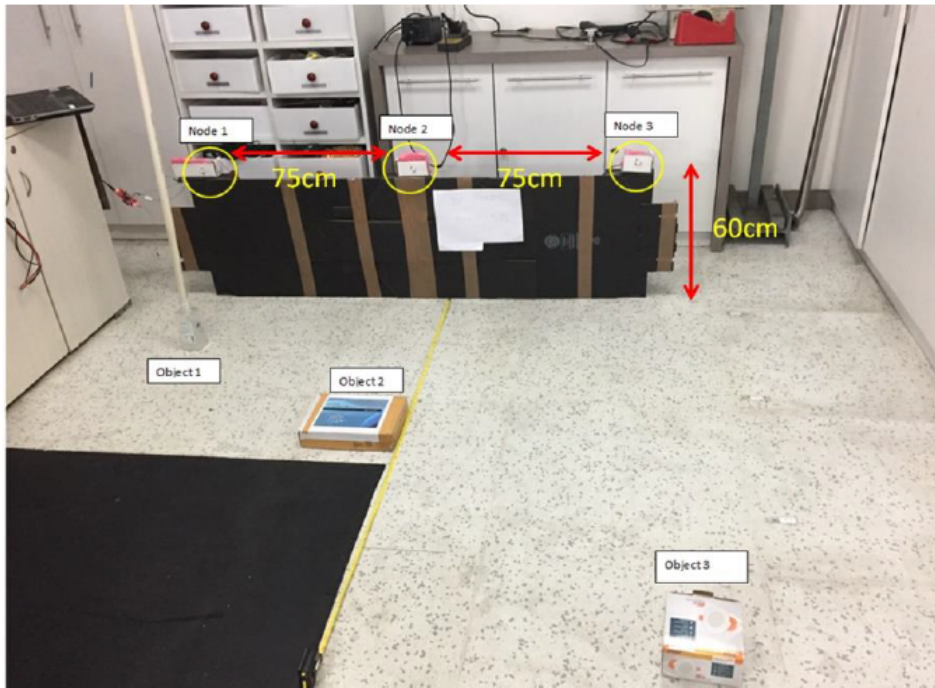


图 15. Test Setup - Object Placement

5.3 Test Results

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

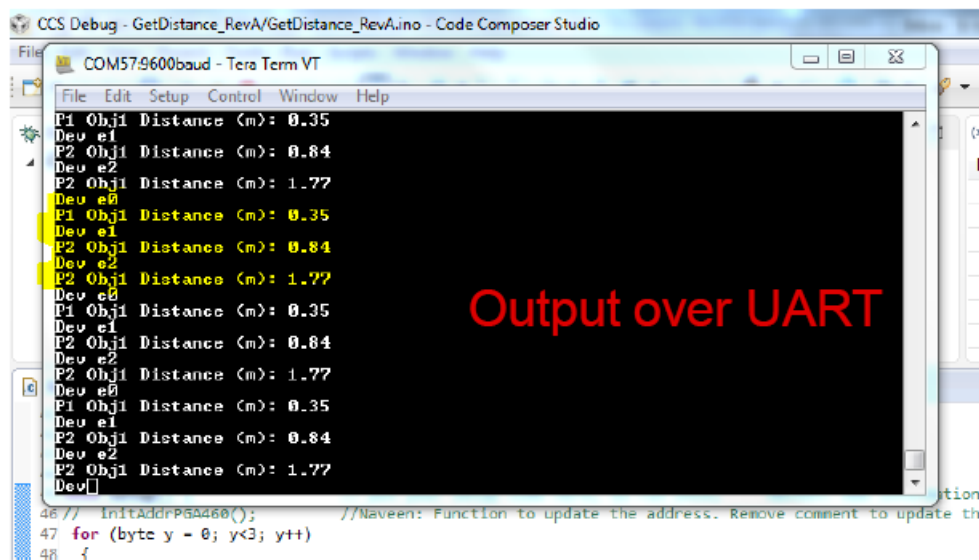


图 16. Output Over UART

```

COM57:9600baud - Tera Term VT
File Edit Setup Control Window Help
PGA460-Q1 8-Sensor UART & OWUI Bus Demo
Instructions: Configure the EUM by entering a byte value between 0-9 per request
1. Communication Mode: 0=UART, 2=OneWireUART ... 2
2. UART Baud Rate: (9600 * BYTE) + 9600 ... 0
3. P1 and P2 Thresholds: 0=25%, 1=50%, or 2=75% of max ... 1
4. TUG's Analog Front End Gain Range: 0=32-64dB, 1=46-78dB, 2=52-84dB, or 3=58-90dB, x-Skip ... 1
5. Fixed TUG Level: 0=25%, 1=50%, or 2=75% of max, x-Skip ... 1
6. Command Cycle Delay: 10ms * BYTE ... 1
7. Bulk TUG Write: 0=false, 1=true ... 0
8. Bulk Threshold Write: 0=false, 1=true ... 0
9. Number of Devices on Bus: 1-8 ... 3
Configuring the PGA460 with the selected settings. Wait...

ADDR 0 : 1 2 3 4 5 6 7
-----
0.30 0.84 1.65
0.30 0.84 1.65
0.30 0.84 1.67
0.30 0.84 1.67
0.30 0.84 1.68
0.30 0.84 1.67
0.30 0.84 1.70
0.30 0.84 1.70
0.30 0.84 1.71
0.30 0.84 1.71
0.30 0.84 1.71
0.30 0.84 1.71
0.30 0.83 1.70
0.30 0.83 1.70
0.30 0.83 1.70
0.30 0.83 1.70

```

Output over OWUI

图 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 商标

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