Ultrasonic Module Pulse-Echo Test Procedure

PURPOSE AND SCOPE

This document provides information and general guidelines for “pulse-echo” testing of Chirp ultrasonic modules. The goal of the process outlined herein is to ensure parts meet the specifications set by Chirp. Deviation from the recommendations contained in this Application Note could result in Chirp sensors not operating properly or failing the test at an unacceptable rate.

EQUIPMENT REQUIRED

- Benchtop test stand or equivalent
- I^2C interface board
- 10-flat flex cable (FFC) to connect module under test to I^2C interface board
- USB-A to USB-B cable to connect computer to I^2C interface board
- Computer with I^2C software to communicate with the sensor using the I^2C interface board

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1 INTRODUCTION

1.1 PULSE-ECHO MODULE TESTING

This document describes a method of characterizing Chirp ultrasonic sensor modules commonly referred to as “pulse-echo” testing. In this test mode, the module under test launches/transmits an ultrasonic pulse having a known frequency. (The exact frequency of the pulse is determined in a short calibration sequence automatically conducted when the module is first turned on.) Upon launching the acoustic pulse, the ASIC (Application Specific Integrated Circuit) in the sensor starts counting using a pre-calibrated clock and switches from transmit mode to receive mode. In receive mode, the sensor captures echo signal(s) reflected from target(s) having the same frequency as the transmitted pulse. A received echo signal exceeding a specified threshold value is deemed to be due to the successful location of a target, at which point the clock stops counting. The final clock value gives the round-trip ToF (time of flight) of the pulse, from which the distance to the target (range) is subsequently calculated by the ASIC.

The concept of pulse-echo testing is illustrated in Figure 1. Initially, the module under test on the left side of this figure acts as a transmitter and transmits the original acoustic wave (in red) towards the target object, as depicted by the blue sphere on the right in the figure. Directly after launching the original wave, the module under test becomes a receiver, and waits to detect the reflected wave (in green) which has been reflected from the object a distance r away. A timer circuit in the module records the time between sending and receiving of the pulse, from which the distance r is calculated. For a given module type, to first order, the intensity of the reflected signal will be a function of the target object size and shape, as well as the distance to the target.

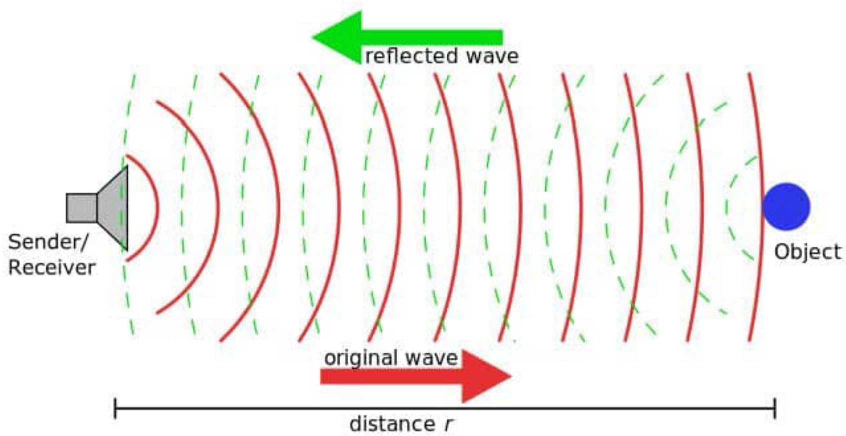


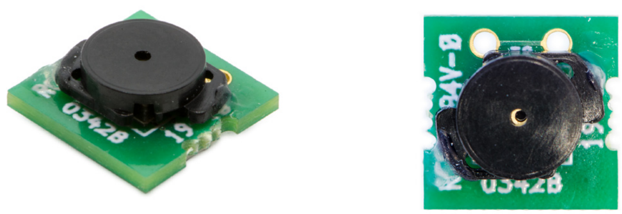
Figure 1. Pulse-echo testing concept.

Based on the brief description given above, we can readily imagine the minimum requirements for repeatably and reliably testing ultrasonic modules in pulse-echo mode. First of all, we need to be sure the desired target echo signal is the strongest and most prominent echo received by the module; no other stray or random echoes should interfere with or distort the primary echo, or the range measurement will be incorrect, non-repeatable, or both. Secondly, the distance between the target and module should be well-controlled with minimal variation. To achieve this, both the module and the target need to be rigidly mounted and robustly fixed in position relative to each other. Finally, to assure adequate reflected signal amplitude, which in turn yields repeatable and reliable range measurements, the appropriate target size, shape, and position must be used to test the specific module type in question.

In this document, we describe the general features of a test system meeting these requirements. First, in the next section, we will give the user a description of typical ultrasonic modules.

1.2 THE ULTRASONIC MODULE

The Chirp ultrasonic module is a PCB to which a CH101 or CH201 ultrasonic range-finding sensor package has been mounted. For improved acoustic performance, a “cap” or acoustic horn is applied to the top of the sensor package. Figure 2 (a) shows a photograph of a typical CH101 module, with the PCB (green) and a circular acoustic cap. Figure 2 (b) shows a top view of the module. The two holes in the PCB at the top of the image are alignment holes, which assure correct orientation of the module in the socket of the test system, to be described in more detail later. In this example, the test system socket has two pins, which go through the alignment holes in the PCB and prevent the module from being placed incorrectly in the test socket. Different customers may have different module designs, but provisions should be made for alignment features to assure precise location and orientation of the module in the test socket. The small aperture at the center of the acoustic cap seen in Figure 2 aligns with an aperture in the center of the test system baffle plate. The aperture allows acoustic signals to be transmitted from and received by the module under test during the characterization sequence. Details regarding the test system socket and baffle plate will be discussed below.



(a) **(a)**

Figure 2 (a). Photograph of a CH101 module; the sensor package is obscured by the circular acoustic cap.

2 (b). Top view of module showing two alignment holes at the top edge of the PCB.

The alignment holes assure proper orientation of the module in the test stand socket. Exact positioning of the alignment holes in the PCB as well as the geometry of the acoustic cap will vary, depending on the specific module type (CH101 or CH201) being tested.

The remainder of this document describes example test system hardware and software used to measure the acoustic performance of Chirp ultrasonic modules. A specific user’s PCB or acoustic cap/interface may vary, so this document only gives general guidelines one should follow in order to use a test system that is specifically designed to accommodate the user’s individual testing and mechanical requirements.

2 TEST SYSTEM DESCRIPTION AND SETUP

2.1 BENCHTOP TEST STAND DESCRIPTION

A mechanical drawing of a pulse-echo test stand for characterizing Chirp modules is shown in Figure 3; an itemized part count of the numbered items in Figure 3 are given in Table 1. The basic function of the test stand is to perform a pulse-echo measurement using a flat 300 mm x 300 mm target (22) spaced 300 mm away from the sensor module. For the system shown, all components are mounted on a standard optical breadboard (20). The module being tested is inserted in a socket (1), which is attached to a socket riser block (6), which in turn is mounted on a base plate (5). The module is held in place by the hinged baffle plate (2), which, when lowered, firmly holds the module and assures good electrical contact between the module and spring-loaded pogo-pins located in the socket assembly, which will be discussed in the next section.

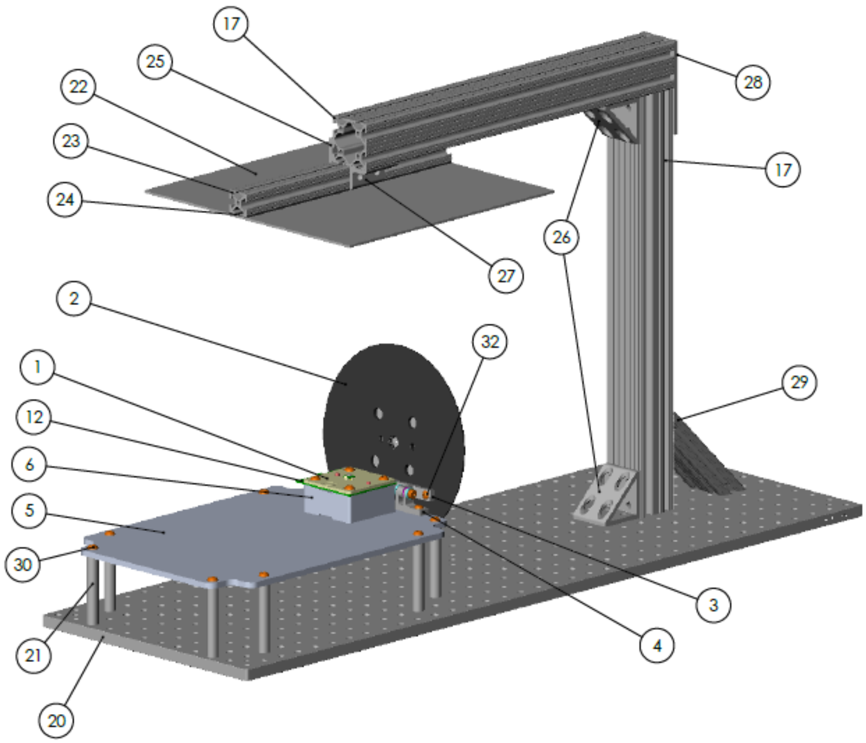


Figure 3. Mechanical drawing of a benchtop test stand.

With the baffle in the “open” position, the module is placed in the socket with the aperture of the module’s acoustic cap facing upwards, while spring-loaded pogo pins in the socket make electrical contact at the back of the module PCB. Alignment pins in the socket fit holes in the PCB assure the module can only be placed in the socket in one correct orientation. Once the module is positioned in the socket and the baffle lid is closed, an aperture in the baffle allows acoustic signals to be transmitted from and received by the module during testing. Near the top of the test stand described here, a 300 mm x 300 mm flat square plate or “target” (22) is mounted horizontally and positioned approximately 300 mm above the module. The target is held rigidly to the system baseplate by a vertical beam (17) that is approximately 400 mm from the module. With this configuration, the primary echo detected by the module should be from the target positioned 300 mm above the module; a secondary echo will be seen at 400 mm due to the vertical beam (17). Of course, depending upon the type of module being tested (CH101 or CH201) and the acoustic interface or cap, the dimensions of the target, the target geometry, and the distance between the target and the module may vary. A key requirement of the test system is mechanical rigidity and robustness such that the target-to-module distance remains fixed during the testing of many modules, irrespective of the final target size, shape or distance used.

During testing, ultrasonic signals that are emitted upwards by the module held in the baffle hit the target (22), and are reflected downwards back to the module, where they are detected and the time of flight of the acoustic signal is measured in order to calculate the distance to the target. As mentioned earlier, this mode of sensor operation is the so-called “pulse-echo” mode where the module first transmits an acoustic pulse and then waits and “listens” for the returned echo. We need to emphasize that the baffle design and geometry shown and described here is just one example of a baffle plate. In particular, the baffle design and geometry will change depending upon the transducer type (CH101 or CH201) as well as the design of the acoustic cap or horn mounted on the ultrasonic transducer package. While one function of the baffle plate is to securely hold the module under test, the baffle plate is also part of an acoustic interface that can affect the performance of the ultrasonic module.

It needs to be emphasized that reflections from the target should be the first signals detected by the module. This is assured only when the target is the closest object to the module. Omnidirectional modules, like the one shown in Figure 2, are particularly sensitive to the presence of other objects near the test station because an omnidirectional module will emit ultrasound with nearly equal amplitude over a hemisphere. This means the transmitted ultrasound will impinge with equal strength all objects that surround the module in three dimensions of the hemisphere. This isotropic beam pattern may result in undesired reflections and signals from objects other than the target if they are within range of the module. This is seen in Figure 3, where we show the hemispherical beam-front of a module centered at position Tx in a baffle. Here, we assume the beam pattern is isotropic, meaning any object closer than *r - in any direction* - will cause a reflection that might be erroneously mistaken for the target. The user should be particularly careful of objects placed to the side or front of the test station (“clutter”), lest they be mistaken for the target. Sensor modules with a more focused beam-pattern are less sensitive to clutter.

We recommend the user capture data both with and without the target present in order to identify and minimize reflections from extraneous objects in the vicinity of the test system. Finally, we suggest placing the test system in an area with low foot traffic, stable temperature, away from heating or cooling ducts, and with minimal air motion from lab equipment such as flow hoods. Air turbulence, wind, and temperature fluctuations are known to cause variations in ultrasonic measurement stability and repeatability. These variations are not due to changes in the modules themselves, but rather due to variations in the medium the ultrasonic waves travel through - the air in the vicinity of the test system.

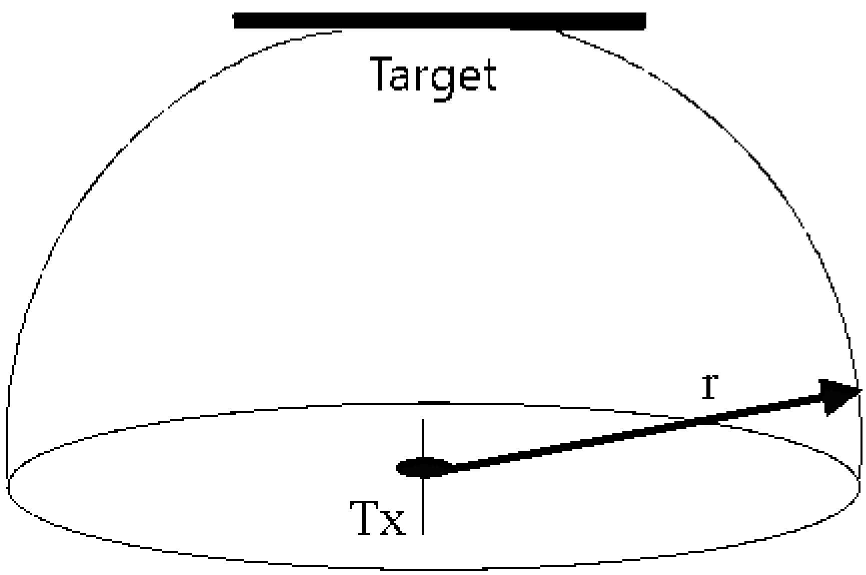


Figure 4. Hemispherical radiation pattern from an isotropic ultrasonic source positioned at Tx with a simple planar target positioned vertically above the source.

Any object closer than r - *in any direction* - will cause a reflection and might interfere with robust target detection.

In Figure 3, we see the circular baffle (open in this figure) and the target are both attached to an optical breadboard (20) that contains a regular array of threaded holes. The center of the 300 mm square aluminum target is aligned with the center of the 200 mm diameter circular baffle in this drawing. For optimum test repeatability, the planes of the target and baffle should be as parallel as possible. The tilt angle between the baffle plate and target should be kept below 1 degree (17.5 mrad) in order to give reproducible test results.

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	682	MODULE SOCKET	1
2	684	BAFFLE PLATE	1
3	685	HINGE, BAFFLE-SIDE	1
4	686	HINGE, FRAME-SIDE	1
5	687	BASE PLATE	1
6	688	SOCKET RISER BLOCK	1
7	435	CH101 MODULE (REFERENCE)	1
8	94035A572	PRECISION SHOULDER SCREW, 1/4" DIA, #10-24	2
9	98017A660	WASHER, 1/4" MIL SPEC	4
10	6627K405	PEEK FLANGED SLEEVE BEARING	2
11	91831A011	NYLON LOCKNUT, #10-24	2
12	638	POGO PIN PCBA BREAKOUT BOARD	1
13	90145A501	DOWEL PIN, 3/16" DIA, 3/8" LONG	5
14	CUSTOM	MODULE ALIGNMENT GAGE PIN, 0.80 MM DIA	2
15	91585A091	DOWEL PIN, 1 MM DIA, 10 MM LONG	1
16	93310A537	BUTTON HEAD SCREW, 1/4"-20, 1/2" LONG	8
17	47065T805	8020 T-SLOT FRAMING, 2X2X18"	2
18	695	PSA FOR STAINLESS FOIL	1
19	670	0.05 MM STAINLESS FOIL	1
20	MB1236	OPTICAL BREADBOARD	1
21	92510A577	SPACER FOR BASE PLATE	8
22	9057K129	FLAT ACOUSTIC TARGET	1
23	47065T411	8020 T-SLOT FRAMING, 1x1x12"	1
24	75935A13	3M VHB 4929	1
25	47065T257	8020 T-SLOT FRAMING, 2x2" FLAT BRACKET	1
26	47065T893	8020 T-SLOT FRAMING, 2x2" OPEN GUESSET BRACKET	2
27	47065T237	8020 T-SLOT FRAMING, 1x2" CORNER BRACKET	1
28	47065T262	8020 T-SLOT FRAMING, 2x4" FLAT BRACKET	1
29	47065T187	8020 T-SLOT FRAMING, 2x6" DIAGONAL BRACE	1
30	92949A556	BUTTON HEAD SCREW, 1/4"-20, 3.5" LONG	8
31	1370N33	RUBBER BUMPER	1
32	93310A260	BUTTON HEAD SCREW, #10-32, 3/8" LONG	4

Table 1. Itemized parts list for the benchtop test stand of Figure 3.

2.2 BAFFLE AND SOCKET

As mentioned previously, the module to be tested is placed in a socket under the baffle plate for testing. The plate is hinged to facilitate inserting the module in the test socket. The baffle plate is held closed by magnets and is opened by pulling vertically on the front of the baffle. A photograph of an open baffle seen from the side of the test system is given in Figure 5 (a). In this figure, we also see a module placed in the socket. In the foreground of the image we see the FFC ribbon cable, which is used to make electrical connections between the socket and test hardware, to be described in a later section of this document.

Figure 5 (b) shows the baffle in the closed, or operating position. The red circle in this photograph shows the location of an aperture in the center of the baffle which allows ultrasonic signals to be emitted and received by the module during testing. The alignment of this aperture and the aperture in the acoustic cap or horn attached to the module (see Figure 2) is critical for obtaining good acoustic performance of the module and reliable measurement results. The aperture in the module acoustic cap must not be obscured or blocked when the baffle is closed. Furthermore, the top of the module acoustic cap should mate flush with the baffle material. There should be no gaps or spaces between the acoustic cap surface and the baffle material.

(a) **(b)**

Figure 5 (a). Photograph showing the open baffle and test socket. A module has been placed in the test socket.

5 (b). Baffle as seen during testing. The red circle shows an aperture in the baffle plate which allows ultrasonic signals to be transmitted and received by the module during testing.

When testing omnidirectional sensor modules like those shown in Figure 2, the shape of the baffle plate is important in assuring good test repeatability. When ultrasonic waves are emitted by an omnidirectional module, the waves are generally emitted in a hemispherical beam pattern from the center of the baffle plate, emanating outward in all directions. As a result, acoustic energy impinges not only on the target as desired, but on anything within the working range of the sensor. Obviously, extraneous items in the beam path will cause unwanted reflections that may interfere with the reflection from the target. In addition, when the transmitted acoustic waves reach the baffle edges, the waves get diffracted and appear as a secondary source of acoustic energy incident upon the target. These “edge waves” may then appear in the reflected signal and corrupt the measurement. The effects of edge waves can be reduced by making the baffle shape asymmetric or irregular; the appropriate baffle shape can result in a significant attenuation of the edge wave reflections. One baffle shape we have found useful for reducing edge wave interference is the irregular pentagon, as seen in Figure 5 (b).

A zoomed-in image of a typical test socket and module is given in Figure 6. As indicated in Figure 2, the module PCB being tested here has two alignment holes. In addition to spring-loaded pogo pins used for making electrical contact to pads on the bottom of the module, the test socket has two alignment pins that need to be oriented with the two alignment holes of the module PCB. The alignment pins in the socket and the alignment holes of the PCB are highlighted in Figure 6. If the module is not placed correctly in the socket, electrical contact to the module will not be made and the baffle lid will not fully close. Damage to the module and/or baffle may occur if the module is not oriented correctly in the socket when the baffle is closed.

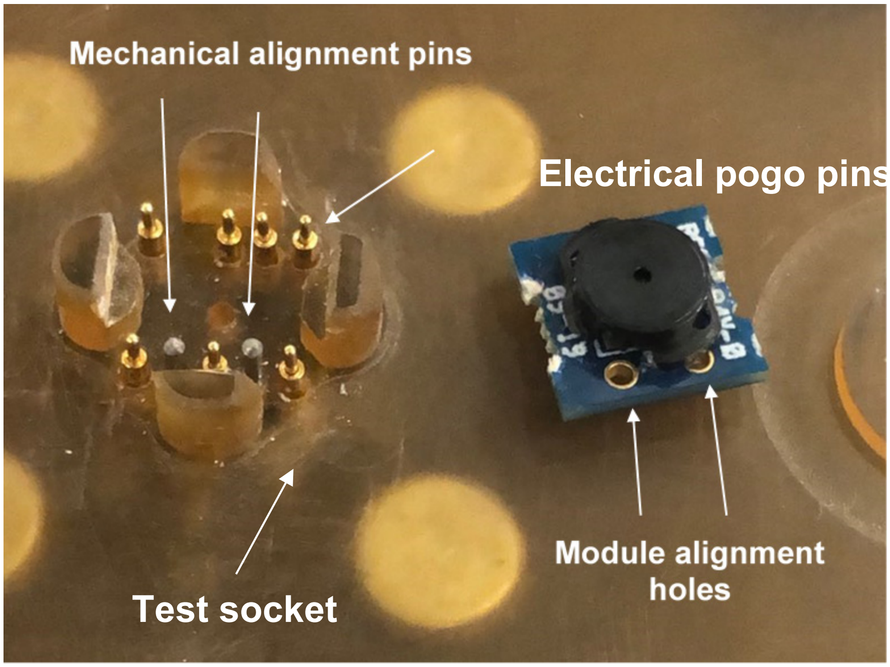


Figure 6. Zoomed-in image of test socket and a module

The socket contains several spring-loaded pogo pins used to make electrical contact to pads on the bottom of the module (not shown). The mechanical alignment pins of the socket need to be aligned with alignment holes in the module PCB before the hinged baffle plate is closed.

2.3 TYPICAL MODULE TEST RESULTS

It should be noted the type of module being tested (CH101, CH201, CHx01), the acoustic interface or horn mounted on the module and/or baffle, the size of the target, and dimensions of the test system will determine some of the measured test results. For example, frequency and bandwidth will be functions of the acoustic interface to varying degrees. The target size, test system dimensions, and acoustic interface can significantly affect the measured Amplitude and Bandwidth.

In Table 2 we show typical measurement results for modules tested using our benchtop module test system. The table shows the range of key parameters expected for a test system when testing omnidirectional Chirp modules shown in Figure 2 and having part number MOD_CH101-03-01.

PARAMETER	MINIMUM	MAXIMUM	UNITS
Frequency	173	180	kHz
Bandwidth	3.5	12	kHz
Amplitude	2000	9000	LSB
Range*	-4	+4	mm

Table 2. Key parameter measurements for MOD-CH101-03-01 modules tested on a typical benchtop module test system

Deviation from actual range with target at 300 mm.

3 REVISION HISTORY

REVISION DATE	REVISION	DESCRIPTION
03/03/2020	1.0	Initial release
08/04/2020	1.1	Updated document with new test guidance and more detailed test procedure

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