Application Report

Ultrasonic Transducer Selection for Gas Metering

TEXAS INSTRUMENTS

ABSTRACT

This report describes a method that can greatly reduce the amount of time required to evaluate and select ultrasonic transducers for gas metering applications.

Although transducer characteristics such as sensitivity and zero-flow drift are often highlighted by manufacturers, consistency in impedance temperature shifts over transducer production lots are critical to the cost-effective mass production of high-accuracy gas meters.

After applying the comparative method described in this report to multiple pairs of transducers from various manufacturers, 200-kHz Jiakang transducers, 400-kHz Ceramtec transducers, and 500-kHz Wuxi Lianhui transducers were all found to have less than 0.5% variation across multiple transducer pairs.

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Trademarks

1 Introduction

When evaluating ultrasonic transducers for gas flow sensing applications there are various properties which should be considered. These include sensitivity, bandwidth, frequency response, and zero flow drift.

The sensitivity of a transducer can determine the standard deviation in measurements at low flow rates. More sensitive transducers require fewer power-consuming measurements to give an accurate result at low flow rates.

Broad bandwidth (50 kHz) transducers can also provide a lower standard deviation because more frequency information can be encoded into the excitation. Broad bandwidth transducers can provide more accurate absolute time of flight measurements over the range of operating temperatures because there is less of a dependency on the resonant peak of the frequency response.

Consistency in the frequency response across transducers in a production lot over the range of operating temperatures is critical for narrow band (30 kHz) transducers to ensure a common configuration and calibration procedure can be used in mass production.

The zero flow drift of the delta time of flight over the range of operating temperatures for transducers is critical to the minimum detectable flow a meter is capable of because variations in the delta time of flight over temperature cannot be calibrated for at room temperature due to cost associated with calibrating individual meters over the range of operating temperatures on the production line.

Demo source code and schematics are provided to accelerate the development of ultrasonic sensing applications. The files can be downloaded from USSSWLib_Gas 02_30_00_03.

For more information on the example code and GUI used in this application report, see *Ultrasonic Sensing Subsystem Reference Design for Gas Flow Measurement*. This application report uses the standard example and GUI without modification.

2 Sensitivity and Bandwidth

For gas flow sensing, sensitivity is a key consideration in determining the frequency of the transducer used. 400- or 500-kHz transducers may be preferred over 200-kHz transducers for smaller flow tubes because they can give lower variations in measurements. 200-kHz transducers may be preferred for larger tube designs in which the ultrasonic signal may be more attenuated. Figure 2-1 shows the attenuation curves for different frequency transducers in 100-kHz increments at different methane concentrations.

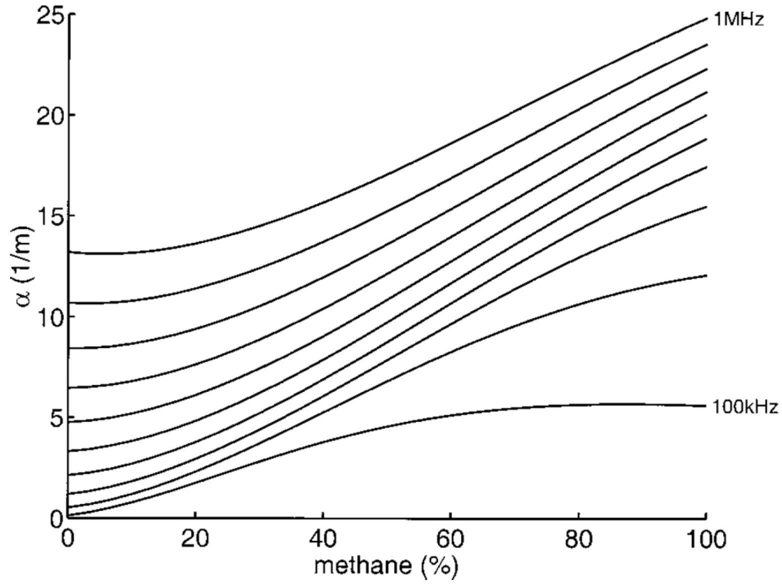

Figure 2-1. Ultrasonic Attenuation in Methane in 100-kHz Increments

Gas flow transducers typically comprise a piezo-ceramic element which is glue bonded to a ceramic or steel face. This face is commonly mounted with a rubber grommet to the flow tube. Consistency in the glue interface to the steel or ceramic face is critical to ensuring repeatable sensitivity and bandwidth across manufacturing lots. Figure 2-2 shows a gas ultrasonic transducer that has the mounting grommet peeled back to expose the piezo-ceramic.

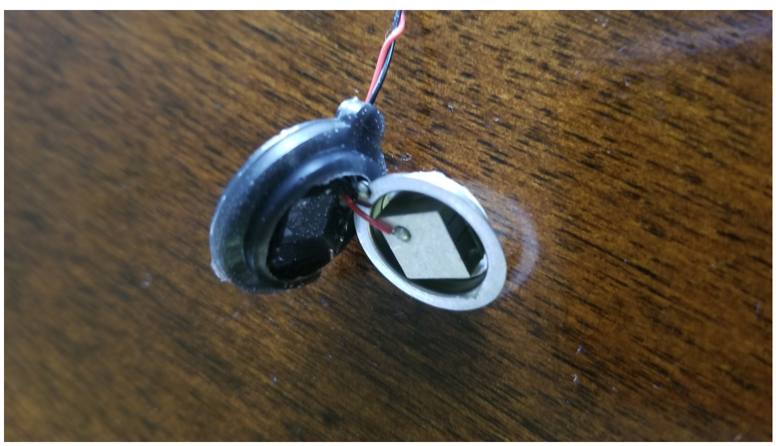

Figure 2-2. Typical Ultrasonic Transducer Construction

In addition to the frequency of the transducer, the sensitivity of the transducer itself has a direct impact on the standard deviation of measurements.

Narrowband transducers (20-kHz bandwidth) exhibiting a stronger excitation response can give a lower standard deviation in measurements but are more susceptible to variations in frequency response over temperature.

Broadband (50-kHz bandwidth) transducers can give a lower standard deviation in measurements with less susceptibility to variations in frequency response over temperature, but may not have enough sensitivity to give a strong enough signal in some tube designs.

More information on standard deviation testing can be found in Ultrasonic sensing subsystem reference design for gas flow measurement.

3 Variations in Frequency Response

Variations in the materials (for example, the glue that is used to bond the piezo-ceramic to the transducer face) and methods used to manufacture transducers can yield variations in the frequency response of these transducers. These frequency response variations can yield variations in the absolute time of flight measurement, which results in lower flow sensing accuracy.

If the transducers are broadband (50 kHz), a common excitation band may be found across transducer pairs that can reduce these variations over temperature. If the transducers are narrowband (20 kHz), it is critical that the frequency response of these transducers shift in a consistent way over temperature.

Figure 3-1 shows frequency response variations seen between two transducer pairs from the same manufacturer. As can be seen from this figure, the variation in frequency response(and sensitivity) between 24°C and –30°C for pair 8892 is greater than it is for pair 3145. More details on how to measure the frequency response can be found in the quick start guide.

Variations in the frequency response as shown in Figure 3-1 can result in absolute time of flight measurement variations of more than 3%.

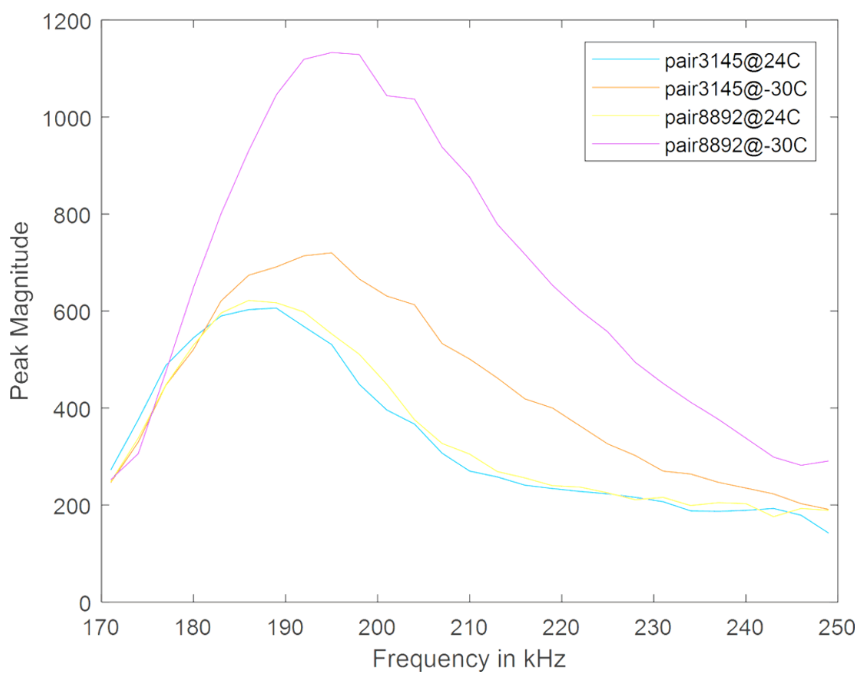

Figure 3-1. Variations in Frequency Response Across Transducer Pairs Over Temperature

For narrowband transducers, variations in frequency response over temperature across transducer pairs can be minimized via a combination of transducer manufacturing and screening methods. Figure 3-2 shows reduced variations in frequency response of transducers from the same production lot depicted in Figure 3-1 that have been screened.

Variations in the frequency response of transducer pairs as shown in Figure 3-2, can result in absolute time of flight measurement variations of less than 1%.

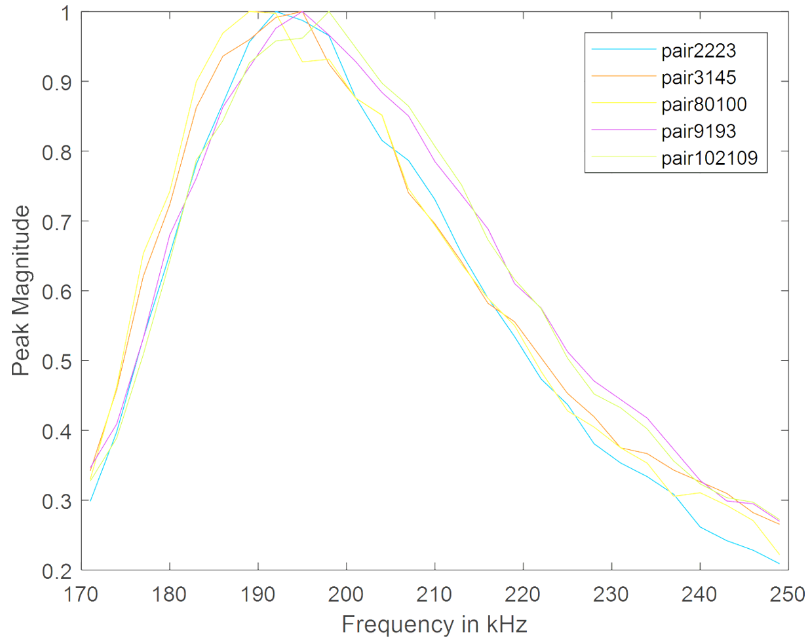

Figure 3-2. Variations in Frequency Response After Screening

When evaluating transducers, it's important to also determine how these transducers will vary in reported flow volumes over temperature. A simple test involving two tubes in series with a fan in an oven can be conducted to determine how much variation might be expected at various flow rates. Figure 3-3 shows a typical test setup.

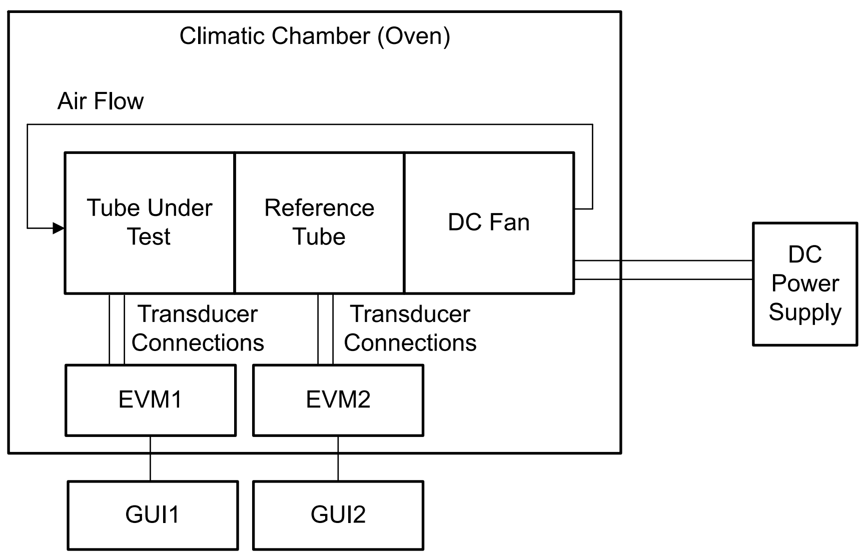

Figure 3-3. Comparative Testing of Transducer Pairs Setup

In this test procedure, a single transducer pair(in one tube) is used as a reference while the second tube with another set of transducers, represents the device under test (DUT).

The ratio between the reported volume at a given flow rate is first recorded at room temperature(with oven door closed and oven off). The oven is then brought to an operating temperature extreme and turned off(55C). The ratio between the two reported volumes is then computed. The percent difference in the ratios at 24°C and 55°C represents the percentage of error drift between the two transducer pairs between 24°C and 55°C.

The temperature is subsequently taken to another operating extreme and turned off (-10°C). The ratio between the two reported volumes is then computed. The percent difference in the ratios at 24°C and -10°C represents the percentage of error drift between the two transducer pairs between 24°C and -10°C.

The transducer pair in the device under test tube is then replaced with another pair of transducers from the manufacturer and these tests are repeated. At least 10 transducer pairs should be tested in order to gather enough statistics to accurately determine the "error spread" across transducer pairs.

Figure 3-4 shows a block diagram detailing this comparative test procedure. After evaluating at least 10 transducers in this way, the differences between the volume ratio errors should also be evaluated. If any two transducer pairs have a difference in percent volume errors that exceed 2x of the percent accuracy requirement at a given flow rate, further testing and evaluation of alternate transducers might be pursued.

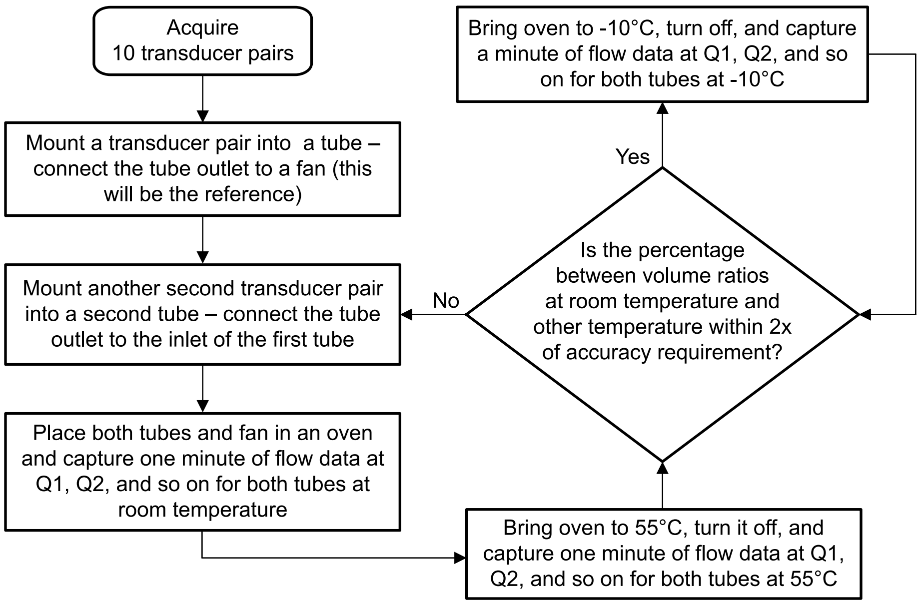

Figure 3-4. Comparative Test Procedure

Figure 3-5 shows the reported volume errors at a flow rate of 60 l/h for two transducer pairs with a third pair serving as the reference.

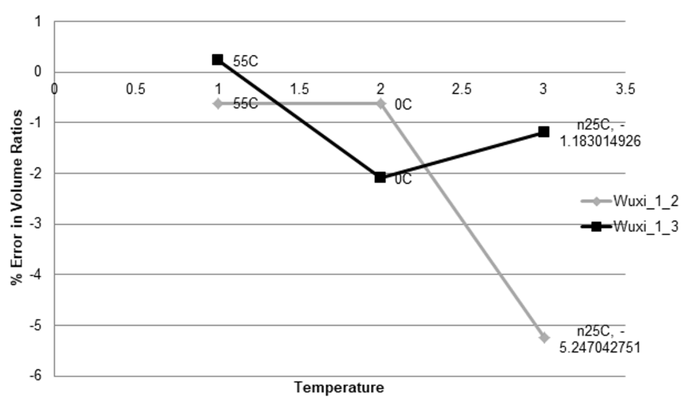

Figure 3-5. Comparative Errors in Reported Volume Ratios

As can be seen in Figure 3-5, the spread between these 3 pairs at 55°C (1%) is much less than the spread at -25°C (5.2%). Assuming additional tests with more pairs all give results within 0% to -5.2% error.

The reported flow results at -25°C would be adjusted by +2.6% to compensate for the mean -2.6% error offset. This should then give an accuracy of ±2.6% at 60 l/h.

This temperature compensation can be made by adding(or subtracting) a relevant number of microseconds from the absolute time of flight result. The temperature of the gas can be determined by averaging the upstream and downstream absolute time of flight measurements if the composition of the gas is known. If the composition of the gas is highly variable(or unknown) a digital thermometer should be added to the design.

If there is too much variation in temperature across transducer pairs, each meter may alternatively have independent temperature calibration parameters stored to nonvolatile memory on the production line.

4 Zero-Flow Drift

The zero-flow drift (ZFD) of a given transducer pair in a given tube determines the minimum detectable flow that can measured by that tube. Zero-flow drift is determined by measuring the maximum variation in the delta time of flight (DToF) with both ends of the tube sealed while the temperature is varied from the coldest (–25°C) to the hottest (55°C) operating temperature. More details on how to measure ZFD can be found in the Ultrasonic sensing subsystem reference design for gas flow measurement.

The zero-flow drift relates to the minimum detectable flow based on the sensitivity of the gas meter. If a gas meter has a sensitivity of 1 ns of dToF corresponding to 1 liter per hour (l/h) of volumetric flow at room temperature, a zero-flow drift of 1 ns would result in a detectable flow that is greater than 1 l/h over the operating temperature of the meter.

It is important to test multiple transducer pairs (>10) from a typical production lot to get a statistical representative of ZFD for a given tube design. As can be seen in Table 4-1, the ZFD varies across 10 transducer pairs from 500 ps to 1500 ps for a set of 10 pairs randomly selected from a typical production lot.

It is important to evaluate a random subset of a typical production lot before investing too much time designing a flow tube for a given transducer. If the manufacturer does not provide a large number of transducer pairs for evaluation, the transducers may be pre-screened and not representative of the flow accuracies that will be seen in production testing.

Table 4-1. Variations in Zero-Flow Drift Across Transducer Pairs

Transducer Pair	ZFD (ps)
1	700
2	500
3	1500
4	1000
5	500
6	1000
7	1500
8	800
9	1000
10	900

Evaluation of transducer pairs 1, 2, and 5 in Table 4-1 alone might yield the wrong conclusion about ZFD and minimum detectable flow for this particular transducer.

5 Summary

When evaluating ultrasonic gas flow transducers, sensitivity, bandwidth, variations in frequency response, and zero-flow drift should be carefully considered.

Narrowband (20-kHz bandwidth) transducers with high sensitivity may require additional screening to ensure frequency response variations over temperature are limited.

Broadband (50-kHz bandwidth) transducers can be less susceptible to frequency response variations but may not have enough sensitivity for some tube designs.

A large number of transducer pairs (more than 10) from a typical production lot should be evaluated for sensitivity, bandwidth, variations in frequency response and ZFD before significant investments are made on tube design.

6 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (October 2020) to Revision B (January 2021)	Page
• Changed Figure 3-3, *Comparative Testing of Transducer Pairs Setup*	3