Achieving higher measurement accuracy using an external amplifier in ultrasonic flow measurement

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Introduction

Ultrasonic flow measurement is gaining wide use in commercial and industrial applications as a replacement to non-static and mechanical measurement methods. Major benefits of using ultrasonic sensors include higher accuracy, reduced maintenance (no moving parts), noninvasive flow measurement, and the ability to regularly diagnose the health of the meter. An example of this ultrasonic time-of-flight (TOF) flow measurement principle is found when measuring the flow rate of liquids or gases, as shown in Figure 1.

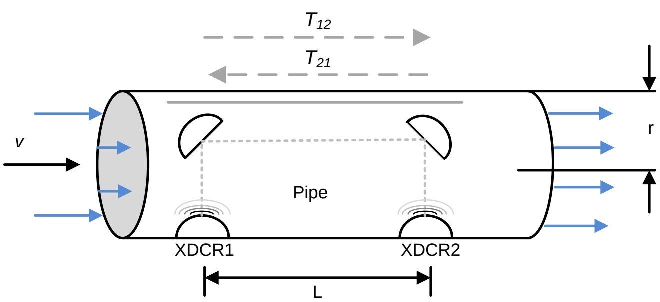

Figure 1. TOF Measurement in an Ultrasonic Flow Meter

In ultrasonic flow measurements, the flow velocity of a fluid or gas is obtained by measuring the transit time difference (TTD) taken by the ultrasonic signal to travel between two transducers (XDCR1 and XDCR2) in the upstream and downstream directions (T12 and T21). As Figure 1 shows, the difference between the T12 and T21 is directly proportional to the flow velocity (*v*). The radius of the pipe is defined as r, and L is the propagation length. For more information on the TOF principle, see TIDM-02003, *Ultrasonic sensing subsystem reference design for gas flow measurement*.

As a result of attenuation in the medium, an amplifier is required in the receive path circuit in order to boost the signal amplitude and accurately measure the ultrasonic signals. This configuration takes advantage of the full input range of the analog-to-digital converter (ADC) in the microcontroller (MCU). When designing the receive path circuit shown in Figure 2, three system-level priorities must be addressed:

- Power consumption
- Signal-to-noise ratio
- Single-shot standard deviation

Power Consumption

For battery-powered applications that do not readily have access to other reliable power sources, such as water flow or gas flow meters, lowering the average power consumption of each component is one of the most important key system-level priorities. Residential, commercial, and industrial flow meters must have an operating life of at least 15 years. The power consumption of a system depends on multiple parameters, some of which can be controlled by the MCU. For more information on MCU parameters, see the customization and optimization section in the TIDM-02003, *Ultrasonic sensing subsystem reference design for gas flow measurement*. For the majority of the system time, the amplifier is off or in shutdown mode. Therefore, the shutdown quiescent current of the amplifier is important for keeping the contribution from the amplifier low. The combination of the operating quiescent current and settling time of the amplifier further minimizes the amplifier contribution to system power consumption.

Signal-to-Noise Ratio (SNR)

The signal-to-noise ratio (SNR) of the system can limit the measurement accuracy of the ultrasonic signal at the transducer. As the signal being measured by the transducer reduces in magnitude or attenuates, the ratio of this signal to the noise in the measurement system starts to diminish. This attenuation of the ultrasonic signal occurs as a result of absorption as the signal travels through the medium. For example, hot methane gas exhibits an over-air attenuation of ~25 dB; therefore, the signal received by the transducer must be amplified by a gain of ~25 dB in order to restore the signal to levels that the MCU ADC can accurately resolve. Figure 2 shows a typical receive path circuit for doing this amplification that includes both the external amplifier and the MCU ADC.

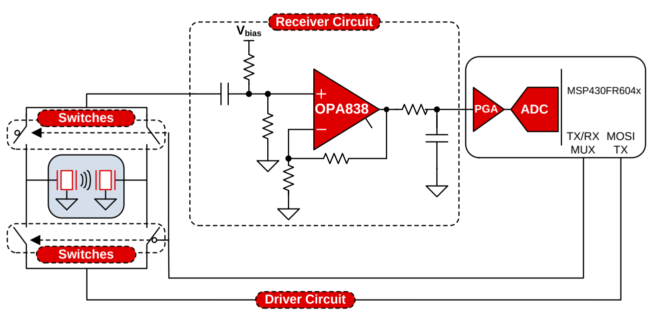

Figure 2. Typical Receive Path Circuit Using the OPA838

Increased dB gain enables longer propagation signal paths, which mean larger pipe geometry, further distance between the transducers, and increased transducer sensitivity for longer contact within the medium. In high-gain applications such as ultrasonic systems, low noise becomes an important parameter because the noise of the amplifier is also amplified, introducing additional noise to the already low SNR system. The noise specification of the amplifier also determines the smallest detectable flow rate. In addition, using an external low-noise amplifier in the front end allows for smaller excitation voltages to be used to excite the transducers because the SNR is minimally degraded by the amplifier. The external amplifier is used in a large-gain configuration; therefore, the low input noise helps achieve optimal levels of SNR while helping to save power on excitation of the transducer.

Single-Shot Standard Deviation (STD)

The single-shot standard deviation (STD) performance determines the expected variance of the measured signal at zero-flow and ambient temperature, and determines the minimum measurable flow at room temperature. The smaller the flow rate, the smaller the TTD (as low as a few picoseconds). Ideally, this value is zero, and results in a perfect measurement of the zero-flow condition. However, any delay offset in the transmitting and receiving circuits directly translates into an STD at ambient temperature. Minimize the phase jitter through the receiving circuit to further reduce the difference that is already present because of impedance mismatches. To minimize the STD, a high gain bandwidth (GBW) amplifier is required. The higher the GBW, the later the phase rolloff occurs, thereby reducing the phase shift introduced by the amplifier.

Figure 3 shows the Δ TOF single-shot standard deviation differences between the OPA836 and OPA838 performances for a 200-kHz system. Actual performance depends on transducers and pipe design; therefore, results may vary.

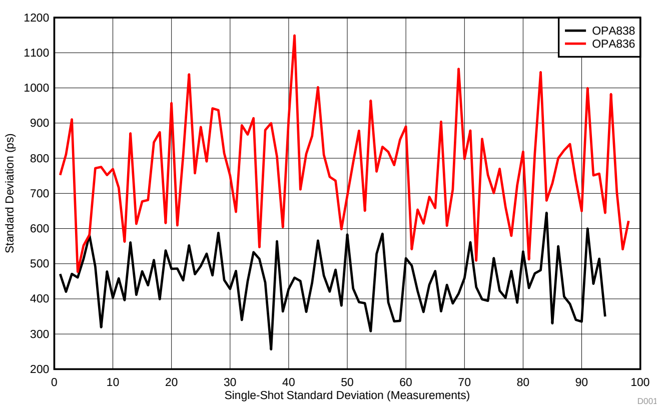

Figure 3. 200-kHz Single-Shot Standard Deviation (STD) OPA838 vs OPA836

The transducer signal frequencies typically chosen fall between 200 kHz to 500 kHz for gas flow meters, and 1 MHz to 2 MHz for water flow meters. Choosing an amplifier with a GBW much higher than the signal frequency minimizes the phase shift introduced. A smaller phase shift means that the output signal is minimally delayed with respect to the input signal. In general, a higher GBW amplifier offers better system phase responses, and results in better edge resolution to detect and make finer measurements without introducing additional measurement error to the STD.

Choosing an External Amplifier

Choose the external amplifier in the receiver circuit of the ultrasonic flow meters to best optimize the three key system priorities: power consumption, SNR, and STD. An example of an amplifier that meets these specifications is the OPA838, with a high GBW (300 MHz), low input voltage noise (1.8 nV/√Hz), and low maximum operating current (1.3 mA) across the entire temperature range (–40°C to +125°C). In the case of flow meter customers, these specs translate into better repeatability for more accurate flow measurements over time.

The OPA838 is a trimmed amplifier that offers a specified shutdown quiescent current of < 1 µA max, and a settling time to 0.1% of ~30 ns. The OPA838 also offers a unique decompensated amplifier architecture that helps achieve industry-leading noise, slew rate, power, and bandwidth performance. Decompensated amplifiers are designed to maximize gain-bandwidth product performance for a given quiescent current value when compared to an equivalent unity-gain stable op-amp. This feature makes the OPA838 a great choice in the metrology analog front end.

There is an entire family of high-bandwidth, low-noise, and low-power amplifiers offered by Texas Instruments. The amplifiers listed in Table 1 help to provide tradeoffs between amplifier specifications that would impact the three system priorities: power consumption, SNR, and STD.

Table 1. Alternative Device Recommendations

System Spec	Amplifier Specs	OPA835	OPA836	OPA837	OPA838
Power	Iq Max (mA)	**0.36**	1.4	0.86	1.3
	Shutdown Iq Max (µA)	1.5	1.5	10	**1**
	Settling Time (0.1%)	60	**30**	35	**30**
SNR	Noise (nV/√Hz)	9.3	4.6	4.7	**1.8**
STD	GBW (MHz)	30	120	50	**300**

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