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Compensation of Zero-Flow-Offset due to Electronics and Transducers Mismatch

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Summary:
Ultrasonic flow meters are widely used in industry for water and gas flow measurements. In practice, those flow meters tend to show a zero-flow error in the time of flight (ToF) measurement that can be suppressed by matching the downstream and upstream transducers in the system. In this work, the effect of mismatch on the ToF measurement is demonstrated for various ultrasonic flow meters under different conditions.

Keywords: Ultrasonic flow meters, flow measurement, zero-flow error, Time of flight measurements, downstream and upstream transducer.

Introduction

The ultrasonic flow meters measure water and gas flow for a wide range of applications. They have the advantage of not having moving parts in the flow, which in turn minimizes the maintenance needs and costs over time. The ultrasonic flow meters are time of flight (ToF) based meters where the transit time difference between the upstream and downstream flow is used to measure the flow velocity. As per [1], ultrasonic flow meters are reciprocal systems, and the only non-reciprocal part of the system is the flow itself. Therefore, in the absence of flow, ideally, the measured time difference should be zero in reciprocal operation [3]. But practically a zero-flow offset is often measured. This offset results in a phase difference between the upstream and downstream measurements. This offset is introduced due to the available mismatch between the up and downstream transducers and simultaneously mismatch in the transducer electronics.

Background, Motivation

The reciprocal operation principle allows for a negligible zero-flow offset measurements [2]. It states that the flow system consisting of piezoelectric transducers, electronics and spool-piece responds same at one side when driven from the other side and vice versa resulting in a small difference in ToF measurement (diff-ToF). For the system to maintain this property, either the impedances of the transducers pair or the impedances of the electronics at both sides need to be matched. This can be analyzed as a two-port network, where the voltage transfer function downstream and upstream can be represented by eq. (1) respectively [3],

$$\frac{V_I^{(2)}}{V_{II}^{(1)}} = \frac{I_I^{(2)}}{I_{II}^{(1)}} = \frac{\left(Z_S + Z_I\right)\left(Z_L + Z_{II}\right)}{\left(Z_S + Z_{II}\right)\left(Z_L + Z_I\right)} \quad (1)$$

Where Z_r, Z_s are the impedance from the electronics in down and up transducer cases.

It is obvious that the voltage transfer functions up- and downstream are identical, when all impedances Z_r, Z_s are identical. In that case, it is important to deduce that the transducer's impedance Z-parameters do not need to be matched as well for the zero-flow offset to be minimized.

Measurement Setup

An ultrasonic flow transducer is placed on the up- and down-stream side of a DN20 water spool piece. An integrated circuit (IC) is added to read out the data and calculate the diff-ToF. The first measurement set is the zero-flow offset in water over a temperature range from 10 to 60 degrees Celsius when there is no flow. The data is averaged over 200 points. The second measurement set is performed by creating a mismatch between the transducer pair by adding a parallel capacitor to either the up- or the downstream transducer which changes its total impedance. The range of capacitance used is from 0 to 220pF, this accounts for 20% of the transducer's self-capacitance which is approximately 1nF. These measurements are performed using the TDC-GP30 board and a competitor board.

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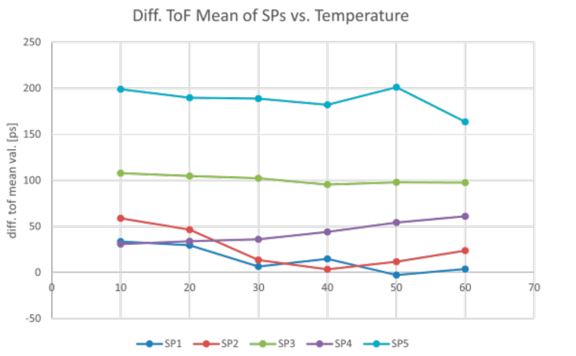

Fig. 1. Diff-ToF measurements with GP30 over the temperature range 10-60°C using different spool pieces.

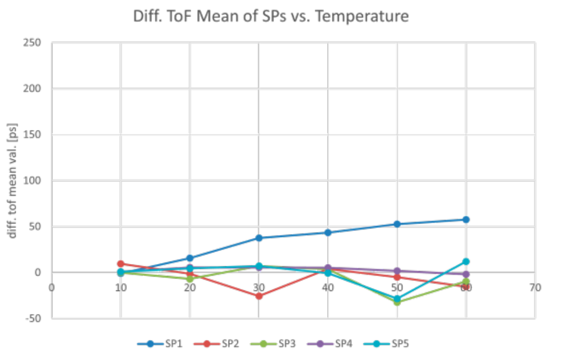

Fig. 2. Diff-ToF measurements with a competitor board over the temperature range 10-60°C using different spool pieces.

Results and discussion

Fig.1. shows the diff-ToF measurements over temperature with GP30. The resulting temperature drift is observed in the diff-ToF values over the different spool pieces, the mean diff-ToF for each spool piece is shown in Table 1. Its minimum and maximum are 12ps and 55ps respectively. Fig. 2. shows measurements on same spoolpieces using a competitor's IC. The span in temperature drift defined as difference in maximal and minimal value of diff-ToF is represented in Table 1. Its minimum and maximum diff-ToF are 7ps and 58ps respectively. The mean part of the offset, which is constant over temperature, is of only of minor importance for application. With compensation in post processing, the offset can be set to zero for both devices. The second measurement is depicted in Fig.3. where both measurements with capacitor on up- and downstream transducers are added using GP30 and competitors' IC. It is performed at room temperature using two spool pieces. When no capacitor is added, the diff-ToF offset is only due to the IC being used which can be compensated as in the first measurement. Then as we add capacitors, the mismatch effect is more pronounced.

Table 1. Span in Temperature Drift

	TDC-GP30 (ps)	Competitor's(ps)
SP1	36.46	58.57
SP2	55.60	35.22
SP3	12.27	39.55
SP4	30.15	7.45
SP5	37.51	40.33

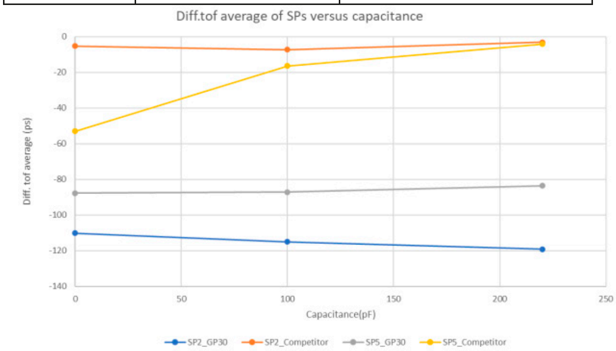

Fig. 3. Mismatch between transducers due to added parallel capacitors from 0 to 220pF.

This effect can be seen using GP30 where the offset is between 4ps and 18ps for both spool pieces. As for the competitor's IC the offset is between 1ps and 48ps with both spool pieces. It can be deduced that the added strong mismatch has only an effect in picosecond range on the intrinsic offset of the chips.

Conclusion

In this work, the zero-flow drift in GP30 and a competitor's IC are presented. It is highlighted that this drift is comparable for both products and is less than 60ps in all cases. This is important for the application. Moreover, in applications with mismatched spool pieces, the effect on the diff-ToF is less noticeable for GP30 with a maximum offset of 18ps compared to the competitor's IC with a maximum offset of 48ps.

References

[1] J.Hemp, Flowmeters and reciprocity, *The Quarterly Journal of Mechanics and Applied Mathematics*, vol 41, no. 4, pp. 503-520, 1988.

[2] P. Lunde, M. Vestrheim, R. Bo, S. Smorgrav and A. K. Abrahamsen, 5D-4 Reciprocal Operation of Ultrasonic Flow Meters: Criteria and Applications, *2007 IEEE Ultrasonics Symposium Proceedings*, 2007, pp. 381-386, doi: 10.1109/ULTSYM.2007.105.

[3] P.Lunde, M. Vestrheim, R.Bo, S.Smorgrav and A.K. Abrahamsen, Reciprocity and its utilization in ultrasonic flow meters. *2005 23rd International North Sea Flow Measurement Workshop.*