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A Sing-Around Ultrasonic Low Power Flowmeter

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Abstract: - In this paper, work carried out in developing a low power and low cost ultrasonic flow meter capable of measuring low flow velocity is presented. The implementation based on the sing around method uses low power components: a Xilinx CoolRunner CPLD and a Texas Instruments microcontroller from MSP430 family. The result is a portable solution working with a 3V supply and operating with ultrasonic transducers at 1MHz frequency.

Key-Words: - flowmeter, sing-around, ultrasound, delay, transit-time

1 Introduction

Ultrasonic flow measurement is not a new technology. However, it has recently become something of a hot commodity among other well-represented technologies in the industrial flowmeter market. The two types of ultrasonic flowmeters applied in closed-pipe flow measurements most often encountered in the process industries use either transit-time or Doppler technology.

Transit-time flowmeters use the difference in time for a ultrasonic pulse to travel a fixed distance in the media, first with the direction of flow and then against it. These flowmeters can have one of two operating modes, time domain and frequency domain. Although they work similarly, transmitting pulses from a transducer to a receiver and back again through the flowing media, *time domain* meters use the difference in time between the two trips to provide information on the fluid's motion.

Frequency domain transit-time flowmeters use the same sensors as time domain meters, however the signals are read differently. Time is in not read directly. Instead frequency-domain units convert the time information into a frequency. The difference in frequency is proportional to flow velocity.

Doppler meters work differently than transit-time devices, most using continuous transmission of a single sound frequency rather than pulses. The beam is transmitted into the media at some angle to the direction of flow. Bubbles, entrained solids, or eddies in the flow then reflect or scatter the sound back to a receiver. Motion in these inclusions will cause a Doppler (frequency) shift of the returned signal. The difference between the transmitted and received frequencies is proportional to the flow velocity.

2 Transit-time Flowmeters

The measuring principle of the transit-time method is based upon the direct measurement of the running time of the ultrasonic signals traveling between two ultrasonic transducers – fig.1. The ultrasonic signal running against the direction of flow has a longer travel-time than the ultrasonic signal running with the flow. The difference in transit times is directly proportional to the flow velocity and, when the cross section is known, the flow volume can be estimated.

For the determination of the transit time, an ultrasonic transducer is excited with an electric signal in the form of a square wave signal (sine wave signal). The transducer then transforms these signals, in an ultrasonic wave packet which is sent through the fluid. The travel-time of this wave packet is then measured with another transducer .

The transit-time of the path traveling with the flow is calculated with:

$$t_{12} = L_{12}/(c+v_{12}) \qquad (1)$$

and the transit-time of the path against the flow is

$$t_{21} = L_{12}/(c-v_{12}) \qquad (2)$$

whereby:

L_{12} - The length of the acoustic paths between transducers 1 and 2

v_{12} - The mean value of the velocities along the acoustic path between transducer1 and 2

c – Ultrasound velocity in the measured fluid

The transit-time difference Δt is then approximated with the acceptance $c >> v$ by:

$$\Delta t = 2L_{12}v_{12}/c^2 \qquad (3)$$

For example, with an ultrasound velocity of c = 1450 m/s, a path length of L = 10 cm, and a fluid velocity of v_{12} = 1 cm/s (0,01 m/s), the measured time difference only amounts to Δt = 0.95 nanoseconds.
With the transit-time method, the time measurement must be taken in nanoseconds in order for the smaller flow stream velocities to be resolved with the required exactness. A extension of the transit time method is the *sing-around method* which make it possible to achieve a time resolution down to hundred of picoseconds [1].

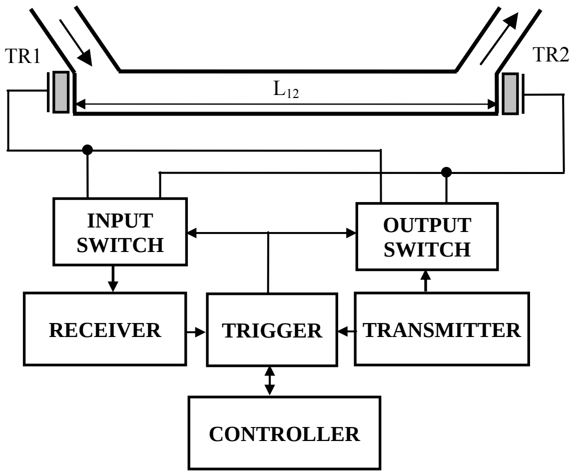

Fig. 1 Block diagram of sing-around flowmeter with axial interrogation

Sing-around method: On a defined path, a short ultrasonic signal is sent from transducer TR1 to transducer TR2- fig. 1. The ultrasonic pulse is received and with the help of a returning signal device, TR1 is triggered to send a new signal. This loop is maintained for N number of sing-around loops. The controller measures the total time it takes to complete the N sing-around loops. The time it takes for the sound to travel between the transducers once in the downstream direction is determined by dividing the measured total time by N. The time required for the sound propagation in the upstream direction is determined in the same manner. Using appropriate electronic circuits is possible to interchange the transducers and to measure directly the transit-time difference for N sing-around loops up and down stream. For this situation equation (3) becomes:

$$v_{12} = (\Delta t^* c^2)/(2N^* L_{12}) \qquad (4)$$

With this method, it is possible to “capture” and “observe” an ultrasonic signal within short, measured distances over as long a period as needed.

The conventional single path sing-around flowmeter measures the sing-around frequency in one direction first and thereafter in the other direction. Here it is assumed that the same electronics is used for both directions. Therefore no matching of electronic delays is required as in the dual path sing-around method. However, if a high accuracy is required, the measuring time becomes relatively long.

3. Implementation

The main aim in implementing a sing-around ultrasonic flowmeter was to obtain a low power, low cost solution. Following this aim was used a CPLD XC2C64 from Xilinx CoolRunner-II family, the industry’s fastest low power CPLD and a Texas Instruments microcontroller MSP430F449.
The MSP430 microcontrollers incorporates a 16-bit RISC CPU, peripherals, and a flexible clock system that interconnects in a ultralow-power architecture which extends battery life The clock system is designed specifically for battery-powered applications. A low-frequency auxiliary clock (ACLK) is driven directly from a common 32-kHz watch crystal. The ACLK can be used for a background real-time clock self wake-up function. An integrated high-speed digitally controlled oscillator can source the master clock (MCLK) used by the CPU and high-speed peripherals.
This combination was chosen in order to accomplish the requirements for high frequency and low power. The CPLD will implement the tasks which require high frequency and time resolution:

- Generation of the emitted burst with the transducer’s frequency – 1MHz
- Detection of the received pulse and trigger of a new emission. This is based on adjusting the level of the received signal related to the hysteresis of the input. For CPLD device each input can selectively arrive through Schmitt-trigger inputs. Approximately 500 mV of hysteresis will be added when Schmitt-trigger inputs are selected.
- Measurement of the difference time between N sing-around loops upstream and N sing-around loops downstream using a reversible counter. The number of the counter cells was set according to the frequency of the free running oscillator, the number N of sing around loops and the distance between transducers detection of the received pulse. For a measurement configuration defined by L_{12} = 0.08m, N=100, c=1450 m/s and the frequency of the free running oscillator = 250 MHz, results a number of 24 cells.

- Free running oscillator for time measurement. According to CPLD performance this frequency can be up to 260 MHz, which provide a measurement time resolution of 4 ns for a single shot transit-time measurement. Depending of the number of pulses the time resolution using sing-around averaging can be lowered to hundred picoseconds.

The MSP430F449 microcontroller must solve the following:

- driving of the measurement cycle
- different parameters calculations based on the transit-time difference Δ*t*
- user interface through LCD display and keyboard
- power management
- calibration of the CPLD free running oscillator using the microcontroller clock generated with external quartz

The result is a portable solution with a minimum number of discrete components, working with a 3V supply and operating with ultrasonic transducers at 1MHz frequency. Table 1 summarizes the device utilization for XC2C64. The figures 2 and 3 presents wave forms including the emitted signal, the received signal and the measured pulse generated from a single shoot measurement.

Table 1 Device utilization for XC2C64

Macrocells used	56 / 64 (87%)
Product Terms used	65 / 224 (29%)
Registers used	30 /64 (47%)
Pins used	31 /33 (94%)
Function Block Inputs Used	94 /160 (59%)

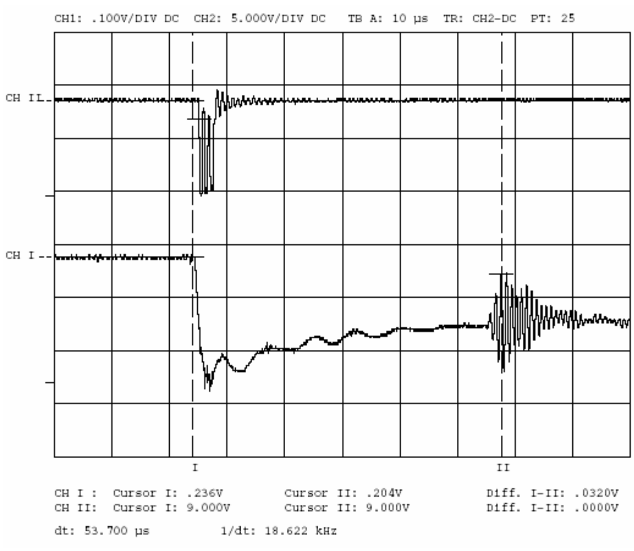

Fig. 2 A single shot measurement: upper – emitted signal, lower – received signal

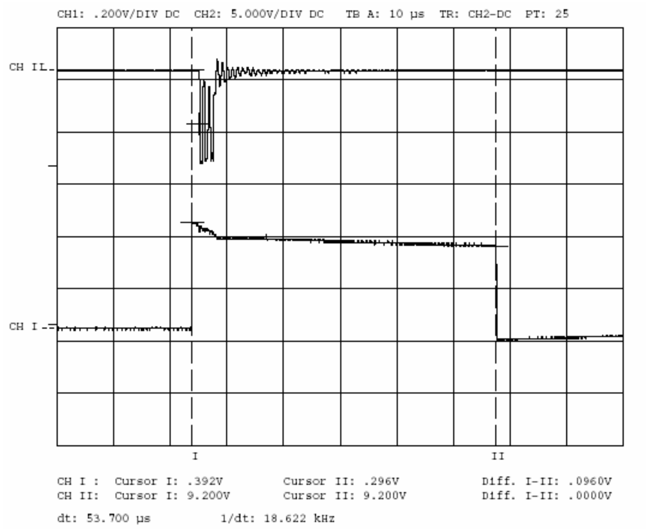

Fig. 3 A single shot measurement: upper – emitted signal, lower – measured pulse (transit-time)

4 Conclusion

A common problem of flow meters is to obtain good accuracy when measure low flow velocities. The implementation based on the sing around method uses low power components: a Xilinx CoolRunner CPLD and a Texas Instruments microcontroller from MSP430 family. The result is a portable solution working with a 3V supply and operating with ultrasonic transducers at 1MHz .

The CPLD is used to generate the emitted burst, to trigger the sending transducer for a new transmission and to counts the time of flight for the sound pulse in both directions between the transducers. The microcontroller then uses the time of flights for different calculations. Based on the above principle, a prototype model was then built and tested. It was found that the system operated as expected. It was also noted that further improvement could be made by controlling the frequency of emitted signal when the temperature of the environment is changed. Work in progress includes further refinements to measurement hardware and software for improving the accuracy and reliability of measurement.

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