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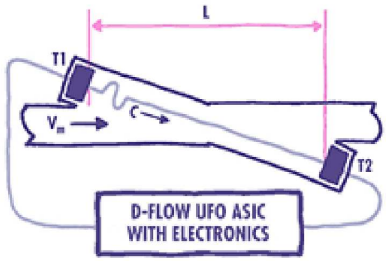
TECHNOLOGY

The D-Flow technology is very versatile and can be used in many different applications. Beside flow measurements, it can also be used for level or distance measurements and speed of sound measurements.

The D-Flow UFO ASIC measures the time of the sound propagation in both directions between the transducers. The sing-around method makes it possible to achieve a time resolution down to a few picoseconds. The micro processor then uses these times for different calculations.

THE SING-AROUND TECHNOLOGY IN A FLOW METER

D-Flow uses a refined version of the sing-around method. One or more pairs of ultrasonic transducers are attached to a meter body. In the figure, one pair of transducers is shown in a diagonal type of flow meter with one upstream and one downstream transducer.



A sing-around loop is established by the UFO ASIC by sending an ultrasound pulse from Transducer 1 towards Transducer 2. The sound pulse is received and fed back into the UFO ASIC, which then excites a new sound pulse from Transducer 1.

This loop is maintained for N number of sing-around loops. The UFO ASIC 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.

Description of variables:
$t1$ = Sound propagation time downstream
$t2$ = Sound propagation time upstream
vm = Velocity of media
c = Speed of sound in the media
L = Distance between transducers
A = Cross-sectional area of the meter pipe
k = Calibration curve
V = Volume flow

The measured downstream time $t1$ that represent the time it takes for the sound to travel between Transducer 1 and Transducer 2 can be expressed as:

$$t1 = \frac{L}{c + vm} \tag{1}$$

L is the known distance between the transducers. The speed of sound c and the fluid velocity vm are both unknown.

In order to be able to solve for the fluid velocity vm independently from the speed of sound c the upstream time $t2$ is also measured. Synonymously with $t1$, $t2$ can be expressed as:

$$t2 = \frac{L}{c - vm} \tag{2}$$

By combining the two equations 1 and 2, the speed of sound c can be eliminated and the fluid velocity vm can be solved as:

$$vm = k\frac{L}{2}\left(\frac{1}{t1} - \frac{1}{t2}\right) \tag{3}$$

By also using the calibration factor k, compensation is provided for flow profile effects among other things. The calibration factor is experimentally determined.

From the fluid velocity the volume flow V can be formed as:

$$V = Ak\frac{L}{2}\left(\frac{1}{t1} - \frac{1}{t2}\right) \tag{4}$$

A is the cross-sectional area of the flow tube.

Most of the companies manufacturing ultrasonic flow meters employ the transit-time method which is a less accurate method to measure the time of the sound propagation. The basic physics are the same for a transit-time flow meter and a sing-around flow meter, but the transit-time flow meter performs only one single sound transmission in each direction. As the sing-around method uses multiple loops the sing-around flow meter benefits from the advantage of a much better time resolution. This is of great importance when measuring small

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flow rates since the time difference between the up- and downstream measurements then is very small. The extreme time resolution of an ultrasonic flow meter based on the sing-around method will allow the flow range to be expanded down to lower flow velocities, still with good accuracy.

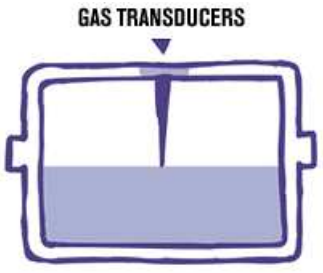
D-Flow's UFO ASIC, the core of the D-Flow technology, contains all major functionality required in an ultrasonic flow meter based on the sing-around method. The time resolution of the D-Flow UFO ASIC can be set to just a few picoseconds. The UFO ASIC is software-adaptable to fit a wide range of flow measurement applications. The ASIC supports two pairs of ultrasonic transducers. This means that one ASIC can support two single-path flow meters or one dual-path flow meter.

THE SING-AROUND TECHNOLOGY IN A LEVEL METER

The same sing-around technology as in D-Flow flow meters can also be used in level or distance measurements applications. The level or distance is determined using the following trivial equation:

$$L = \frac{tc}{2} \tag{5}$$

t is the time for the sound propagation including the bounce back. c is the speed of sound.



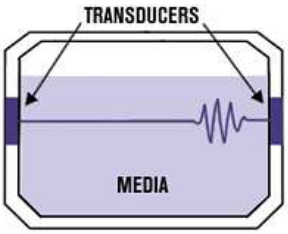
The extreme time resolution in the UFO ASIC is so high that the total uncertainty is dominated by mechanical tolerances and calibration errors. This is shown by the repeatability of a D-Flow based Level meter of $\pm$ 0.01 mm or better.

THE SING-AROUND TECHNOLOGY FOR ANALYSIS

A speed of sound measurement works exactly the same as a flow measurement except that the speed of sound is calculated instead of the flow rate. In for example a flow meter set-up the two equations expressing the two sound propagation times $t1$ and $t2$ from equations 1 and 2 can be used. By combining the two equations the fluid velocity vm can be eliminated and the speed of sound c can be solved as:

$$c = \frac{L}{2}\left(\frac{1}{t1} + \frac{1}{t2}\right) \tag{6}$$

If the fluid velocity is zero (t = $t1$ = $t2$) the expression can be reduced to:



$$c = \frac{L}{t} \tag{7}$$

The total uncertainty of the speed of sound measurement is dominated by the calibration of the distance between the transducers. The repeatability of speed of sound measurements using the D-Flow technology better than $\pm$ 10 mm/s.

UFO ASIC

The UFO ASIC is more than a time measurement circuit. The UFO ASIC comprises almost all electronics needed for accurate measurement of flow, level, and speed of sound measurement. In short, the ASIC has the following features:

- Enables a low cost total solution by few and low cost external components
- There are two low power modes; power-cycling and sleep mode.
- In low powered applications, the low power modes enables 10 year battery lifetime.

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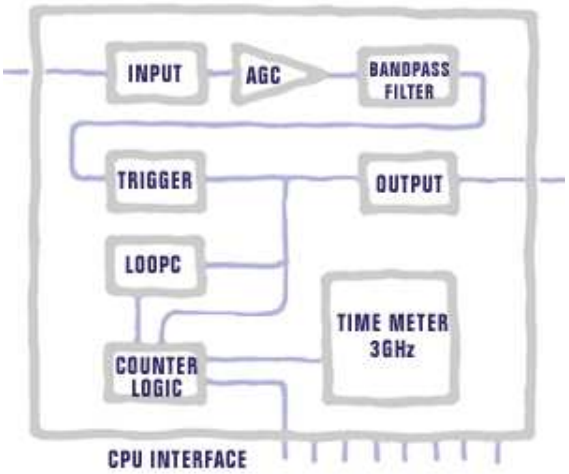
- Typically < 5 ps time resolution using sing-around averaging
- 300 ps or better single shot time resolution
- Optional 3V or 5V I/O communication
- Automatic input gain setting

In addition, the ASIC automatically controls:

1. Transmission of an ultrasonic pulse.
2. Setting of the amplification with an automatic gain control.
3. Sampling of the zero level of the input signal. The time gap to sample the zero level is software selectable.
4. Detection of the received pulse. The detection voltage level is software selectable.
5. Selection of the chosen zero crossing. The software can select where the zero crossing measurement takes place.
6. Transmission of the next pulse and the selection of the sing-around loop for N number of pulses. All parameters are software selectable.
7. Data output. The time data is available for the micro processor to read from the ASIC's readable registers through an 8 bit data bus.
8. The filter for the transducer frequency is external and makes it possible to use a large number of different transducers.

The internal structure of the UFO ASIC is given in the figure above. The analog signals from the ultrasound transducers are received and fed to an amplifier. The signal is amplified to 1 V peak to peak, AGC. The signal path is then routed through an external band pass filter and finally detected in a trigger circuit, TRIGGER. Then the next sound transmission is issued to the desired transducers.

The output signal from the trigger circuit is the sing-around signal. The number of sing-around loops completed, as counted by a loop counter, LOOPC, indicates the number of periods in the sing-around signal. The period time of this signal gives the sing-around frequency. The TIME METER component of the UFO measures the total time of N sing-around loops as programmed



into UFO. This time, tx, can now be read by the microprocessor and used to calculate the flow.

As indicated in the figure, the UFO ASIC can be regarded as a peripheral circuit to a microprocessor. UFO has a standard 8-bit bus communication interface with read, write, and chip select functionality. Via this interface the 16 readable and the 16 writeable registers of UFO can be accessed. Via one register, the microprocessor can issue commands to the UFO. In this way, the microprocessor will start sing-around measurements in the upstream or downstream direction. When the UFO has completed such a measurement an interrupt request is issued. Now the microprocessor can read sing-around period data and start the next measurement. Other commands that the processor can order the ASIC to do are:

- Setting initial parameters for different flow tube length, shapes and flow media.
- Calibration of the received signal through the AGC to obtain a 1V peak-to-peak signal.
- Calibration of the free running oscillator.
- Zero Calibration, to set the different delay times for each transducer and excitation stage.
- Time measurement using low power mode.

The D-Flow UFO ASIC is available in MQFP 44 package.

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ELECTRONICS

The electronics for a complete system include the following parts: The D-Flow UFO ASIC as described above, a micro processor, a power supply, an excitation stage, a communication interface and a temperature sensor.

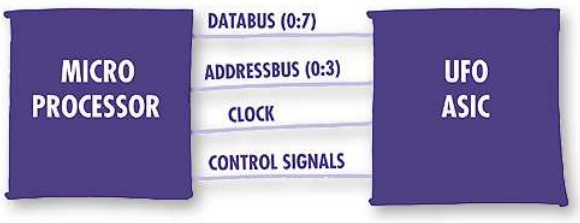
Power supply

The D-Flow UFO ASIC needs 5V for the analog part and 2.7 - 5.5 V for the digital part. The ASIC also needs a 2.5 V reference. Preferably the microprocessor use the same voltage as the digital part of the ASIC. Depending on the transducers to be used, another voltage for the excitation may be required.

In our electronic evaluation platforms D-Flow uses a single 3.6 V supply voltage together with voltage step-up circuits.

Microprocessor

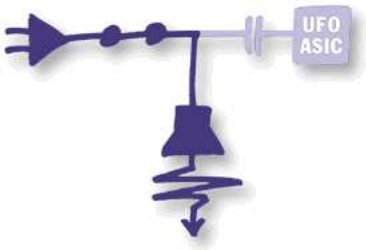
The UFO ASIC can be considered a standard I/O module that must be controlled by a microprocessor. The processor calculates the measured sing-around time data into flow data in a manner that suits your needs. It also controls the communication to you as a user, via a display or computerized control system.



D-Flow has worked with Hitachi H8 and later Mitsubishi M16C microprocessors. If you have a favorite processor family you'll certainly find one that is suitable for your application, though using the Mitsubishi M16C will save you some time in designing the software. The system normally needs an 8 bit or a 16 bit processor with at least 5 kB RAM. The software used in the D-Flow prototypes is about 10 kB. The ASIC needs a reference clock. It is often suitable to use the internal clock of the processor. The clock shall have a frequency of 1 - 16 MHz. For lowest power consumption 1 MHz is recommended.

Excitation stage

Since the D-Flow technology is very versatile and fits a lot of applications, there are a few things that need to be adapted in each case. One is the excitation stage that powers the pulse to be sent by the transducers. The type of excitation stage differs for liquid applications and gas applications. The large difference in acoustic impedance between the transducer and the gas makes it harder to transmit a pulse in a gas than in a liquid. D-Flow has developed a few excitation stages for 5 V up to 200 V and from 250 kHz to 4 MHz of frequency.



Receiving electronics

Since we use the same transducers to both transmit and receive the pulses, the electronics for transmission and reception of the pulses are connected to each other.

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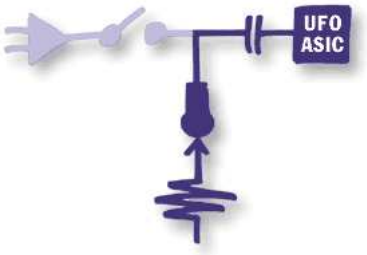
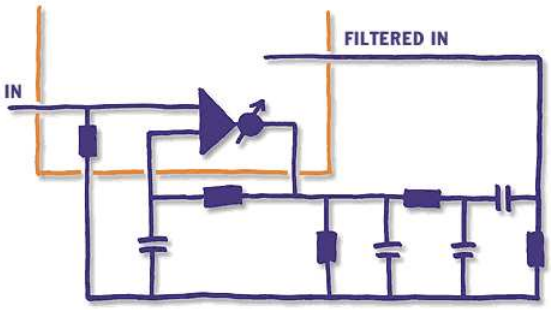


Filter

Another component that needs to be adapted is the filter. The filter is a band pass filter that must be adapted to the frequency of the transducer. In liquid applications we normally use a frequency of 4 MHz and in gas the frequency is 250 - 1000 kHz.

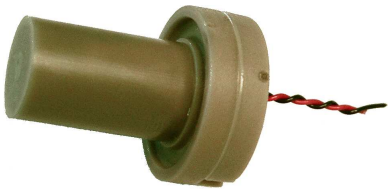


Communication interface

To communicate with the outer world the system needs a communication interface. D-Flow uses an RS232 port that communicates with a PC via optic fiber. D-Flow has also developed a pulse output and a display. Depending on your requirements, you need to develop an appropriate communication. For example: 4 - 20 mA, 0 - 5 V, CAN-bus, Lon works, Bluetooth etc.

TRANSDUCERS

The D-Flow UFO ASIC can handle a large number of ultrasonic transducers with a frequency from 200 kHz up to 4 MHz. D-Flow uses piezo-based transducers for liquid and various gas transducers from sub-suppliers.



COMPANY INFO

D-Flow is a knowledge-based company that specializes in ultrasound technology, mainly for flow measurement. Our knowledge is based on 20 years of research in ultrasonics and flow measurement technology. For further information, please visit *www.d-flow.com*.

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