Transit-time Ultrasound Flow Measurement (TTFM)

TTFM MEASUREMENT CONCEPTS

Ultrasound

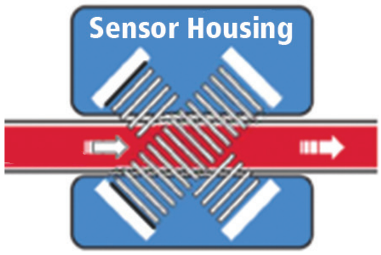
Ultrasound refers to high frequency sound waves that are outside of auditory range. Ultrasound velocity depends on the acoustic properties of the liquid being measured and its temperature. Transonic Flowsensors are calibrated based on known liquid properties and temperature conditions.

Transit Time

Transit time is the length of time it takes for ultrasound waves to pass through the material being measured.

Transit Time = Distance/Velocity

Knowing the time of travel over a given distance allows for the velocity to be calculated.



With X-style configuration of a Flowsensor, four transducers pass ultrasonic signals, alternately intersecting the vessel/ tube in upstream and downstream directions.

Upstream / Downstream

All ultrasound waves begin at the same frequency and velocity. As the ultrasound waves travel downstream or with the flow within the vessel or tube, their velocities increase. As ultrasound waves travel upstream or against the flow, their velocities decrease. Faster flow produces a greater change in ultrasound wave speed. One ray of the ultrasonic beam undergoes a phase shift in transit time proportional to the average velocity of the liquid times the known path length over which this velocity is encountered.

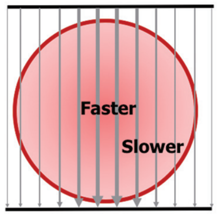
The Flowmeter subtracts the average downstream transit times from the average upstream transit times. This difference is directly proportional to Volume Flow.

Calibration supplies the flow Gain constant (k) which transforms the proportional signal to true volume flow.

$$\text{Differential TT} \times k_{gain} = \text{Volume Flow}$$

Wide Beam Integration

With wide-beam ultrasonic illumination, the receiving transducer integrates these velocity-chord products over the vessel's full width to yield volume flow.



Since time is sampled at all points across the diameter of a vessel or tube, volume flow is independent of the flow velocity profile. Ultrasonic beams which cross the acoustic window without intersecting the tubing or vessel do not contribute to the volume. flow integral..

When measuring flow in vessels with perivascular flowprobes, wide beam illumination allows volume flow measurement even when the vessel is smaller than the flowprobe acoustic window. No assumptions of vessel diameter need to be made to measure volume flow.

TTFM traverses a cross- section of a vessel or tube, measuring average displacement of the liquid through the sensor. It is calculated as follows:

$$\text{Volume Flow} = \text{Integrated Differential Transit Time} \times k_{gain}$$

Transonic TTFM Advantages

TTFM Measures Volume Flow

Transit-time Flowsensors measure the velocity of liquid across the entire vessel lumen to derive VOLUME FLOW in mL/min or L/min. This differs from Doppler technology which derives flow from separate estimates of average VELOCITY in cm/sec of sound particles reflected from the field.

TTFM Measures Flow in Most Liquids

Transit-time ultrasound measurements are not dependent on particulate matter in the liquid in order to measure flow. Liquids such as saline, water and physiological buffers can be measured with transit-time ultrasound, unlike Doppler technology which requires signals to bounce off moving particles such as red blood cells within a liquid in order to measure flow. Even lymph can be measured with TTFM.

Unmatched Zero Flow Stability

The Flowmeter's oscillator drives its transmitting circuitry and functions as the phase reference signal for its sensitive receiver amplifiers and detectors. Direct pickup of the (loud) oscillator signal onto the (far weaker) received signals (via power lines, a capacitive source, or air) can manifest as a zero-flow offset, as it will alter the phase and zero crossings of the upstream/downstream received signals.

If the phase relationship between the transmit and received signal fluctuates due to variations in acoustic transit times as a result of temperature or other liquid property changes, this pick-up signal will exhibit itself in a varying zero flow offset. This effect is indistinguishable from a change in true flow unless the flow is stopped and the flowmeter is re-zero'ed.

Time tested and honed over more than forty years, the sophisticated engineering of Transonic Flowmeters is demonstrated by their hallmark high stability and low, stable zero offset. This same gold-standard performance in now available in ASIC Flowmeter designs!

Mimimally and Noninvasive Technology

The transit-time method requires minimal intervention with the liquid flow stream to provide its flow measurement. For intraoperative measurement on arteries and veins, Transonic Perivascular Flowprobes do not require an exact nor constricting fit on the vessel to provide accurate results, thus making them the method of choice for adequate flow confirmation in CABG bypass and transplant surgeries. Transonic Tubing Flowsensors have no contact with the liquid media to derive volume flow measurements, making the technology perfectly suited for blood pumps or delivery of sterile therapies in high purity conditions.

Sensitivity Scaled to Sensor Size

By using a range of ultrasound frequencies scaled to vessel or tubing size, Transonic Flowprobes and Flowsensors are able to match high resolution measurements proportional to the vessel or tubing size. This allows the instrument to realize super low flows of tenths of a milliliter in the smallest Flowsensors and Flowprobes, while scaling up to 100 L/min using the largest Flowsensors. Pulsatile flows are resolved with picosecond sampling and filtered to present accurate waveforms in real time.

References:

Drost CJ, "Vessel Diameter Independent Volume Flow Measurements Using Ultrasound," Proceedings San Diego Biomedical Symposium 1978; 17: 299-302. US Patent 4,227,407, 1980.

Ultrasound Dilution Technology (UDT)

UDT Theory of Operation

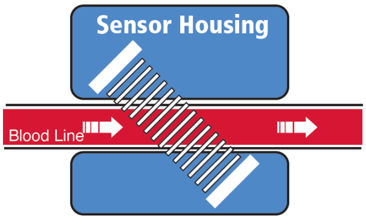
Indicator dilution (UDT) combines two technological principles:

1. Differential Transit-time Ultrasound
2. Indicator Dilution

Each are described succinctly below.

Principle I: Differential Transit-Time Ultrasound

Paired clip-on sensors transmit beams of ultrasound through the blood line many times per second. Transducers pass ultrasonic signals back and forth, alternately intersecting the flowing blood in upstream and downstream directions. The Flowmeter/Monitor derives an accurate measure of the changes in the time it takes for the wave of ultrasound to travel from one transducer to the other ("transit time") resulting from the flow of blood in the vessel/tube. The integrated differences between the upstream and downstream transit times over the distance of the tubing/vessel provide a measure of volume flow.

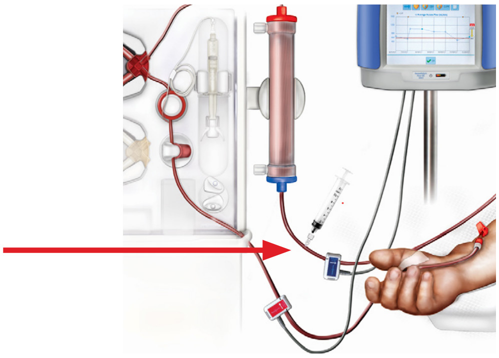


The blood line is inserted into the groove of the flow/dilution sensor body. Direction of flow is indicated by arrows. The ultrasonic beam is shown emanating from the two transducers in the sensor body.

During hemodialysis, extracorporeal membrane oxygenation (ECMO), or cardiopulmonary bypass (CPB), two matched flow/dilution sensors are clipped onto the arterial and venous lines, respectively. The Monitors continuously display both delivered blood flows (one from the arterial sensor and one from the venous sensor). Comparison of the readings with the pump flow setting (i.e., the flow the pump is assumed to deliver) provides an opportunity to identify and correct flow delivery problems.

Principle II: Indicator Dilution

Flowmeters/Monitors coupled with Flow/dilution Sensors measure ultrasound velocity. A bolus of isotonic saline introduced into the blood stream dilutes the blood and thereby reduces the ultrasound velocity of the liquid. Paired Flow/dilution Sensors, attached to an extracorporeal circuit and connected to the Flowmeter/Monitor, sense this decrease in the ultrasound velocity of blood.



Example dialysis circuit with saline injection point shown.

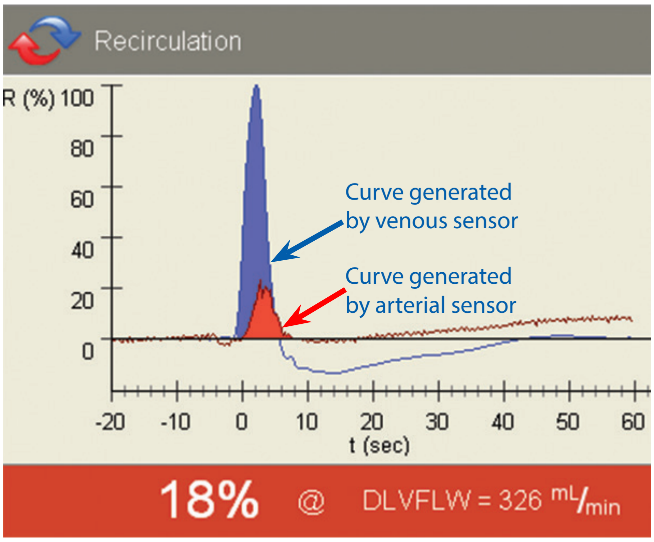
UDT Theory of Operation cont.

Principle II: Indicator Dilution cont.

Flow/dilution Sensors record this saline bolus as a conventional indicator dilution curve. First, the Flowmeter/Monitor displays a curve sensed by the arterial sensor and then a second curve sensed by the venous sensor. The areas under the curves are calculated by the Flowmeter/Monitor using verified dilution equations and are used to determine values for recirculation, vascular access flow, and cardiac output during hemodialysis, recirculation and oxygenator blood volumes during ECMO, and a host of cardiac function parameters during critical care therapy. These results are then displayed on the Monitor's screen.

Ultrasound Velocity

0.9% NaCl: 1533 m/sec
Blood: 1580 m/sec



Transonic Technologies in Action

TTFM and UDT, both developed by Transonic, have become the "gold standard" technologies for capturing and quantifying critical flow-related parameters that can be used by clinicians to make informed decisions about their patient's health status and care. These technologies are used in many industry-leading medical devices for a wide variety of applications, including:

- CP Bypass (heart-lung machines)
- Ventricular Assist Devices (VADs)
- ECMO circuits
- Dialysis systems
- Ex-vivo organ support systems
- Infusion/transfusion/perfusion apparatus

Every day, Transonic strives to advance these technologies and to discover innovative applications that improve and advance the delivery of patient care around the world.