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Improvements in Low-cost Ultrasonic Measurements of Blood Flow in "By-passes" using Narrow & Broad Band Transit-Time Procedures

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Abstract

- **The ischemic cardiopathology is a cause of death, being the by-pass operation an effective approach to reduce morbidity and improve life quality.**
- **In this surgery, the flow in coronary vessels must be measured. The transit time (TTFM), is already an indispensable intra-operative tool.**
- **This work shows improvements in flow-metering, tested under real surgical conditions in Cardiocentro, for narrowband and broadband regimes.**
- **Mathematical models and phantoms were constructed to evaluate with precision flow measurements, in condition near to real vessels, before to perform the design of the electronic systems which include analogic detection, acquisition & pre-processing and a portable PC.**

Generalities

The blood flow through coronary arteries can be measured, in a non-invasive way, using the method known as transit time flow measurement (TTFM), considered nowadays as the most accurate. In fact, it is already an indispensable complement during coronary implants (arterial bypasses) in the surgery processes. An ultrasonic flow-meter using the transit-time technique is based on: an acoustic wave, traveling through a moving medium, has a transit time lesser if it travels in the same sense of the flow and greater if it travels in the opposite.

This work resumes some technological improvement in TTFM blood flow-metering systems designed for narrowband and broadband regimes, in the CSIC and the ICIMAF centres, with funding of a CYTED R&D project. It includes an alternative transduction disposition with simultaneous radiations, and an efficient signal acquisition with a USB compatible display.

Both TTFM systems are formed by a detection module, an acquisition & pre-processing stage and a portable PC. Our acquisition system was upgraded by integrating a PIC18F4550 microcontroller (for obtaining a smaller unit size). A practical software is included offering to surgeons good operation facilities and a more economic and robust flow-metering tool.

TTFM principle

Some fundaments of the ultrasonic TTFM have been presented for narrowband driving [1-2]. In broadband case, we consider a short driving signal e(t). Being h_d (t) the emission impulse response for a differential transducer area, then the ultrasonic signal emitted by this area is: $f_t(t) = e(t) * h_d(t)$

Each infinitesimal pulsed acoustic beam traveling through water, tube walls and the flowing fluid, arrives to the receiver transducer, as a retarded version of transmitted signal ($f_t(t - T(x,y,z))$)

This transit time, $T(x,y,z)$, for an infinitesimal beam, can be expressed as: $T(x,y,z,t) = \int_0^L \frac{dx}{c \pm v_x(x,y,z,t)}$

[$v_x(x,y,z,t)$ is x component of fluid speed and c is sound velocity in the media]

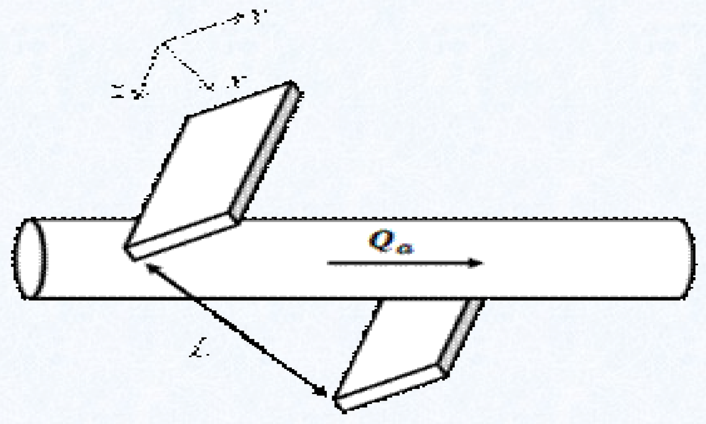
In our case, the fluid velocity can be considered much smaller than the propagation velocity of the beam.

Making an expansion in Taylors series and truncating it, transit time can be approximately written as:

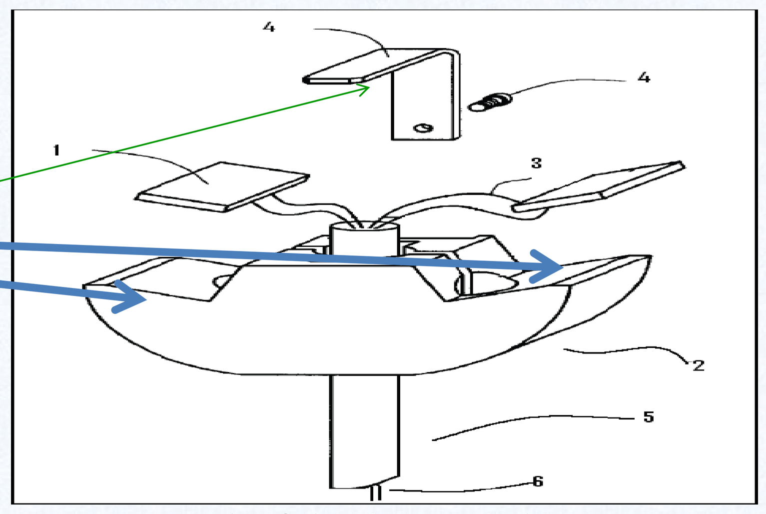
$T(x,y,z,t) = \frac{L}{c} \pm T(v)$, where: $T(v) = 1/c^2 \int_0^L v_x(x,y,z,t)dx$

The total received signal can be obtained by integrating the delayed functions over the whole receiver [1, 3].

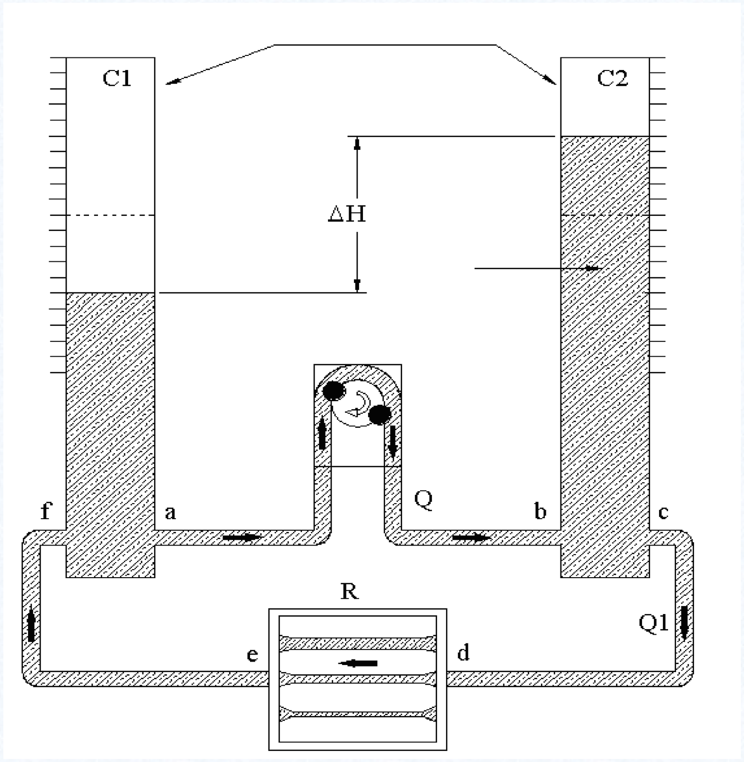
In the practice, the two transducers are located in the same side of the vessel (to see the figure) forming a determined angle between them, and being both united to a common reflector.



Schematic diagram of the physical system in the TTFM technique



Details of the designed ultrasonic probe of bi-transducer type [4]



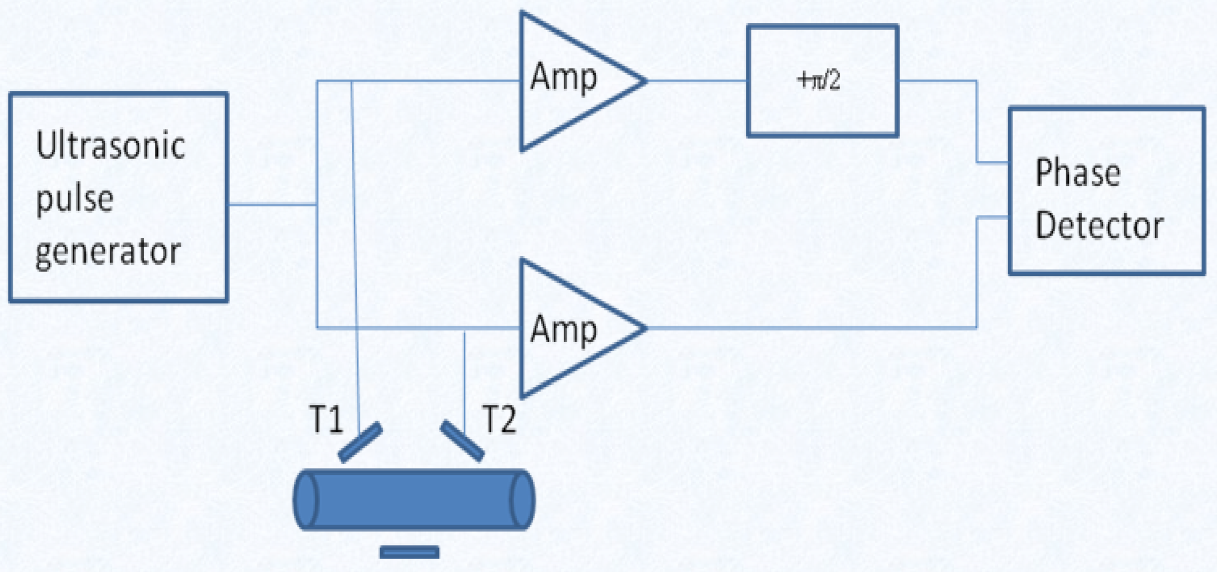
Phantom scheme designed for Transit-Time measurements in our laboratories

Possible non ideal effects

The model of ref. [1], do not take into account the mechanical changes suffered by the vessels during the cardiac cycle. In the reference [3] a model with a major precision is proposed assuming that both, the vessel radius and also the wall thickness, change following the cyclical cadence.

In the narrowband option, the two transducer emit successively in two distinct instants, but in the broadband BB case the two emissions are simultaneous, minimizing influences of the pulsed regime in the vessel movements causing possible perturbations in the flow measurements.

A very general blocks scheme of BB electronic system designed in our laboratory is shown in figure:



Blocks diagram of the TTFM system designed with simultaneous broadband transducer driving

A high-voltage pulser creates very short spikes to properly excite both transducers. It includes tuning and damping devices, and a decoupling circuit to protect both electronic receivers, which contain especial broadband amplifiers with gain in the range of 20 to 60 dB. A special analogic design based on a phase detection in quadrature, assures that the very little time delays ("picoseconds") between the two receiving signals can be found.

The successful design & development of our efficient and accurate TTFM system (with a resolution in the order of mL/min required the use of a phantom very fitted to specific requirements, in order to permit a good calibration of the system, to obtain the absolute value of the measured flow, and to adjust these values for each particular bi-transducer.

Diverse phantom types are used for these tasks, mainly including silicone artificial vessels. The use of these artificial vessels is very convenient because they are economical, durable and simple to achieve. But they differ patently from the real characteristics of a biological vessel in that related to elastic constants. Therefore their use, during the equipment settings, can lead to errors in the measurements. For this reason, the final adjust of our prototypes required some testing under real surgical conditions in Cardiocentro (Havana).

Acknowledgments:

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