Design and construction of an angled ultrasonic transducer applied to blood flow measurement.

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DISCA - IIMAS - UNAM

40th Annual UIA Symposium

23-25 may 2011

University of Glasgow, Scotland, U.K.

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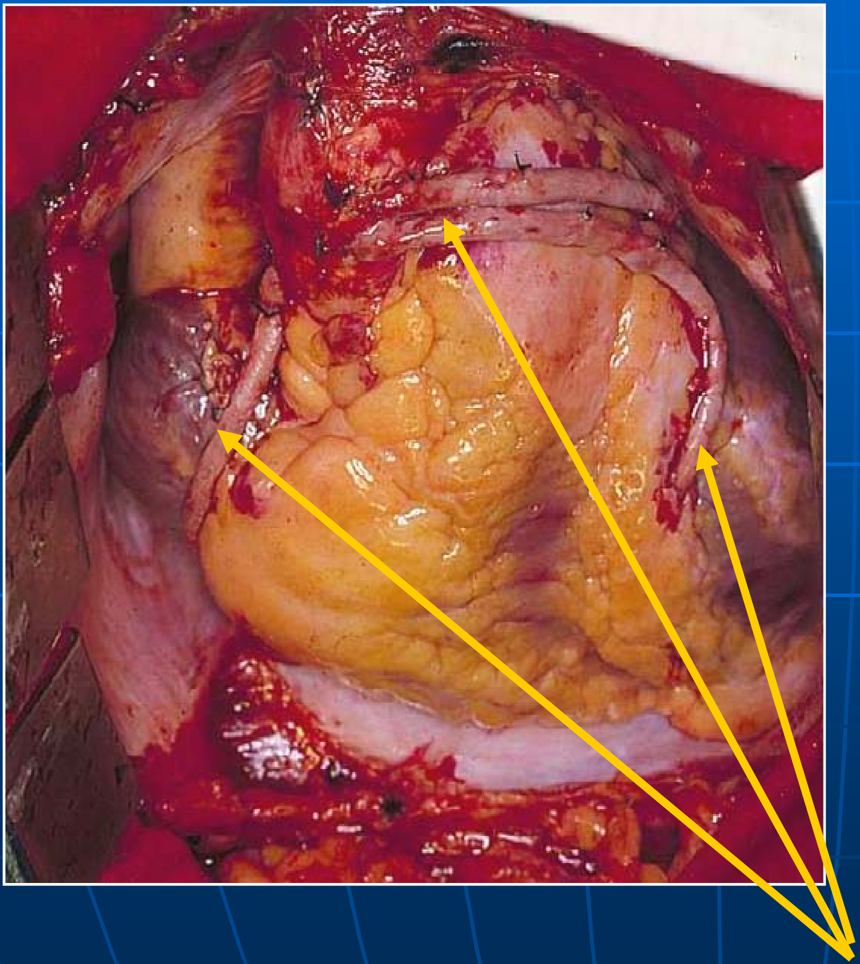
Motivation



- **Doppler ultrasound system for measuring blood flow.**
- **System is intended to be used to assess coronary implants and bypasses.**
- **Quantifying blood flow through implants is an important task to ensure the surgical process.**
- **Reducing both the surgical and death risks.**

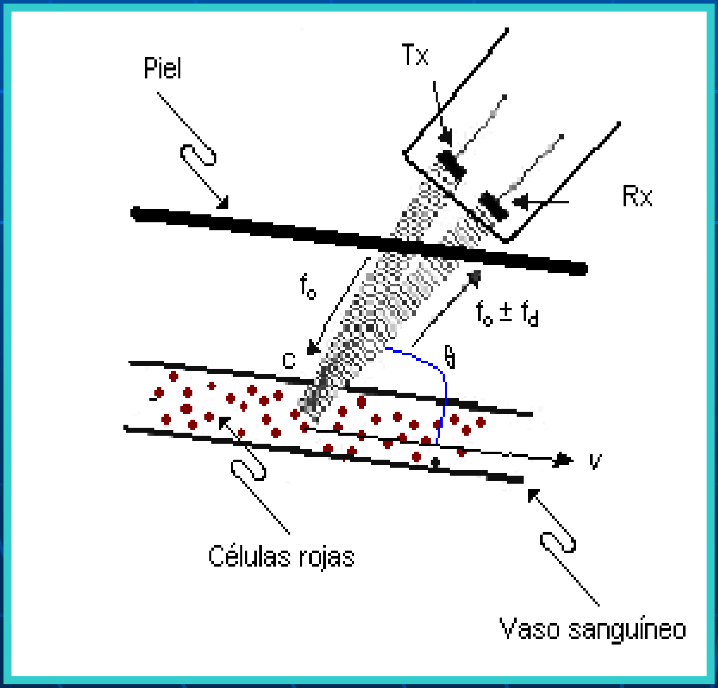
coronary bypasses

Motivation

- Ultrasonic techniques have been successfully used in development of medical diagnosis equipment (e.g. obstetrics, cardiology, peripheral vascular system).
- Instruments based on Doppler ultrasound principles have allowed extracting phase information from the echoes of body moving structures.
- Development of Doppler techniques in conjunction with signal and image processing methods have generated a notorious increment in the use of ultrasound.
- Opening new options and displacing other invasive methods used up to nowadays.

Motivation

- **Doppler ultrasound systems either continuous and pulsed are non-invasive methods for detection and evaluation of the blood flow.**
- **Doppler frequency is proportional to blood velocity in the sampled volume.**



$$f_d = \pm \frac{2v\cos\theta}{c} f_0$$

v = blood flow velocity
(14 - 750 mm/s)

f_o = transmission frequency
(4 to 8 MHz)

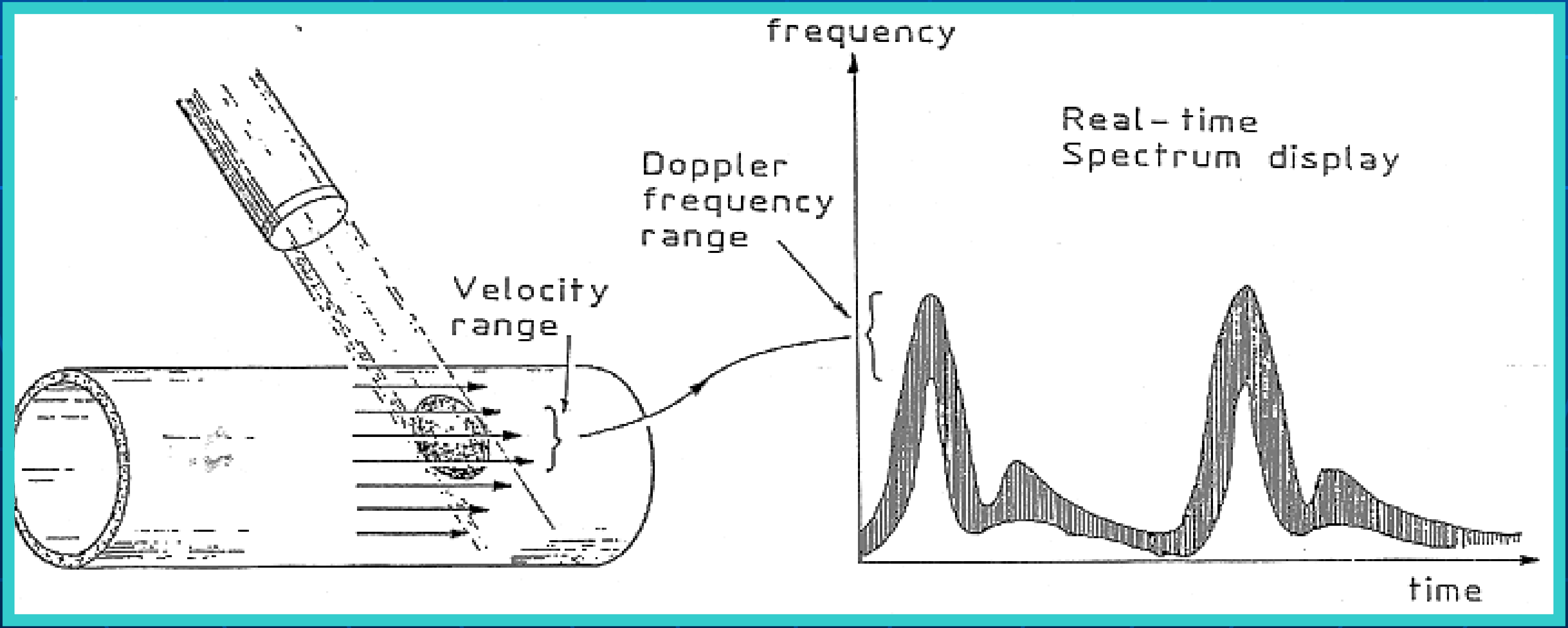
c = blood US velocity
(1500 m/s)

f_d = Doppler frequency
(100 – 7600Hz)

θ =Angle between beam and the flow

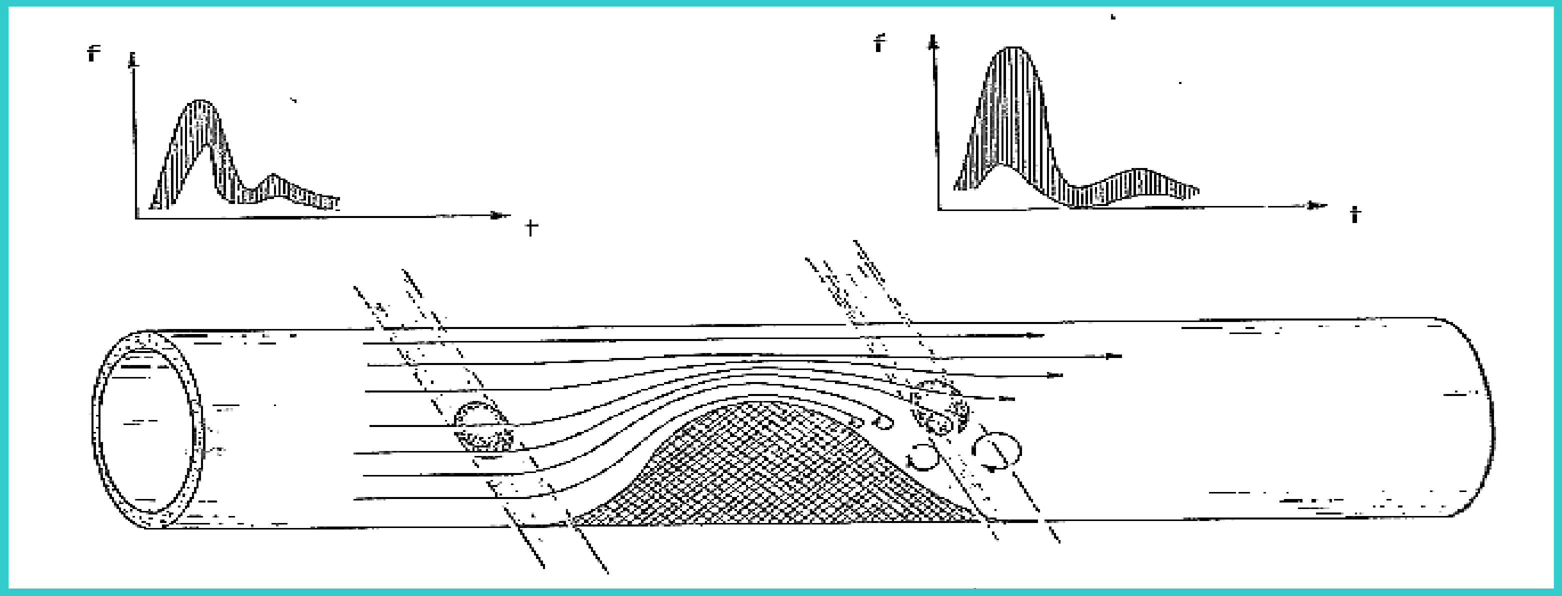
Motivation

- **As the arterial blood flow is pulsed the Doppler signal has a spectrum that varies in the time domain.**
- **In ideal conditions the Doppler power spectrum has a similar form to a blood flow histogram in the sampled volume.**



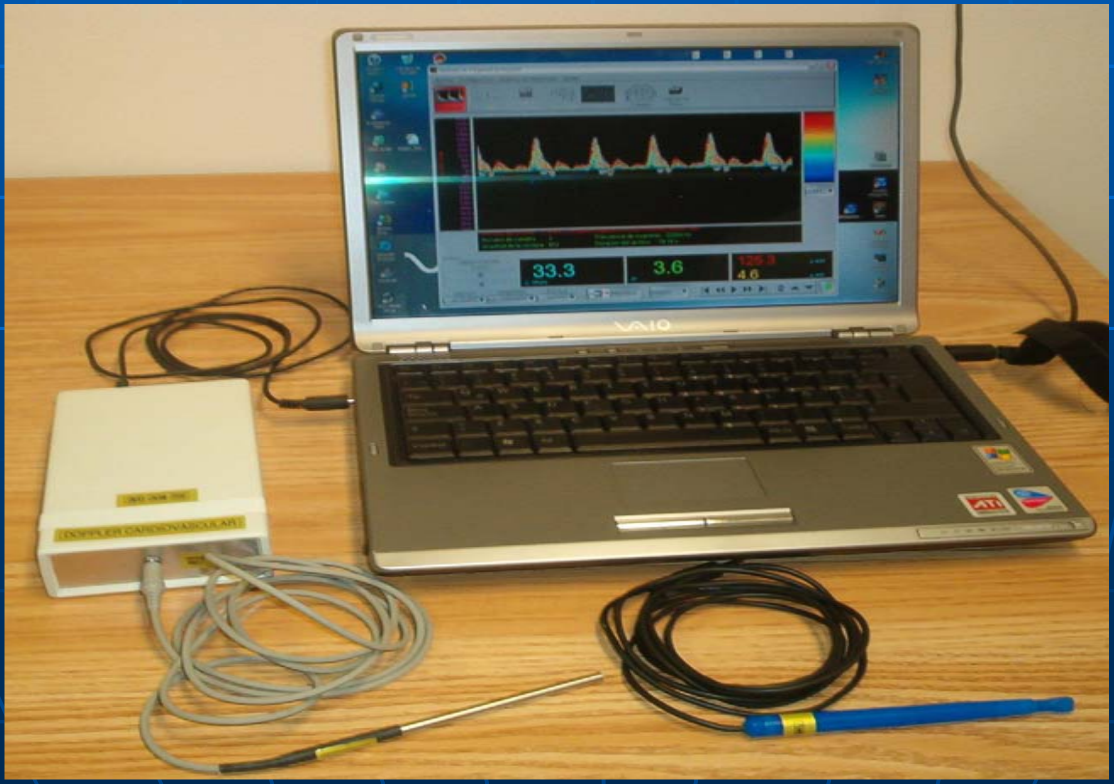
Motivation

- The analysis of the Doppler signal gives relative information to the evolution of the distribution of the blood particle velocity in the artery.
- An increment in the Doppler frequency range as a result of turbulence in the blood flow is typically used to detect artery occlusions and other vascular problems.



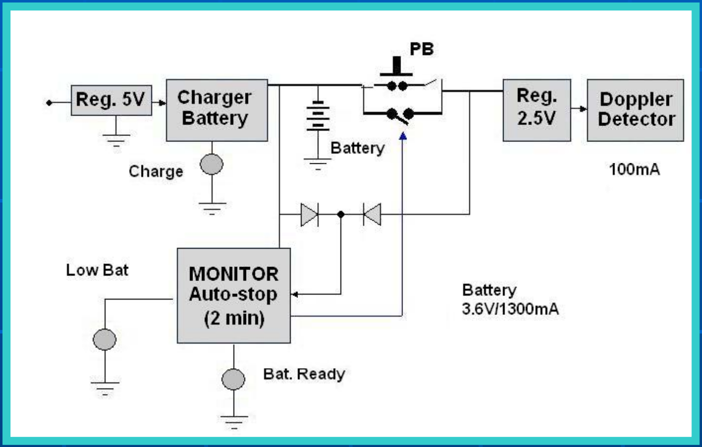
Introduction

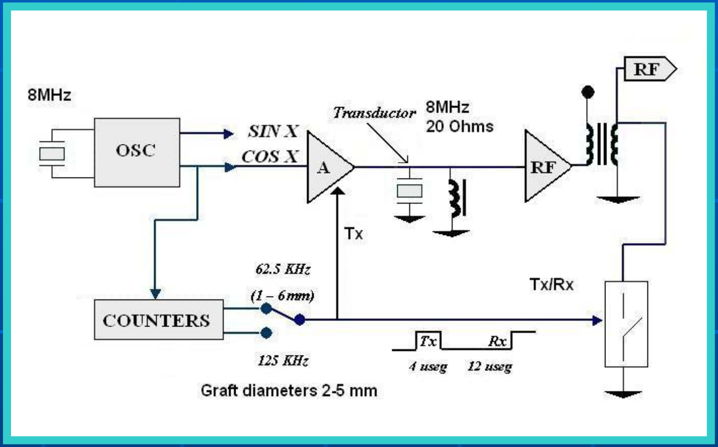
- **The Doppler Ultrasound Blood Flow Measurement System is based on an PC architecture that is portable and low-cost, incorporating the advantages of expensive systems with dedicated hardware.**

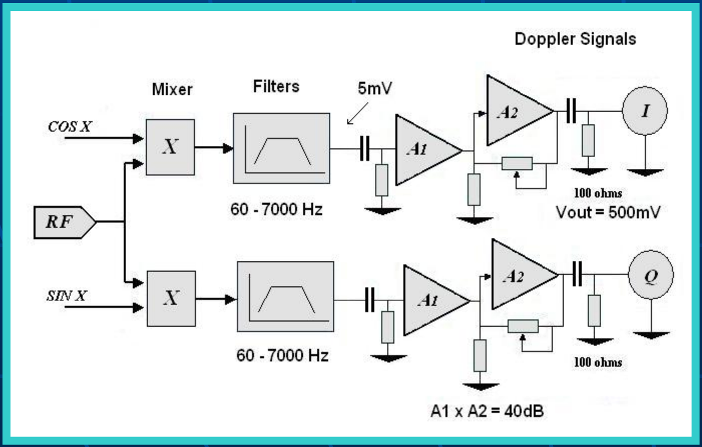


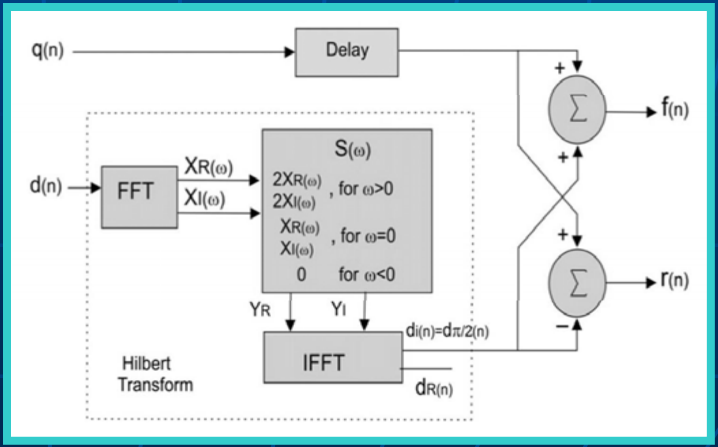
Introduction

- **The system incorporates a pulsed-wave bi-directional Doppler ultrasound flow detector working at 8 MHz.**



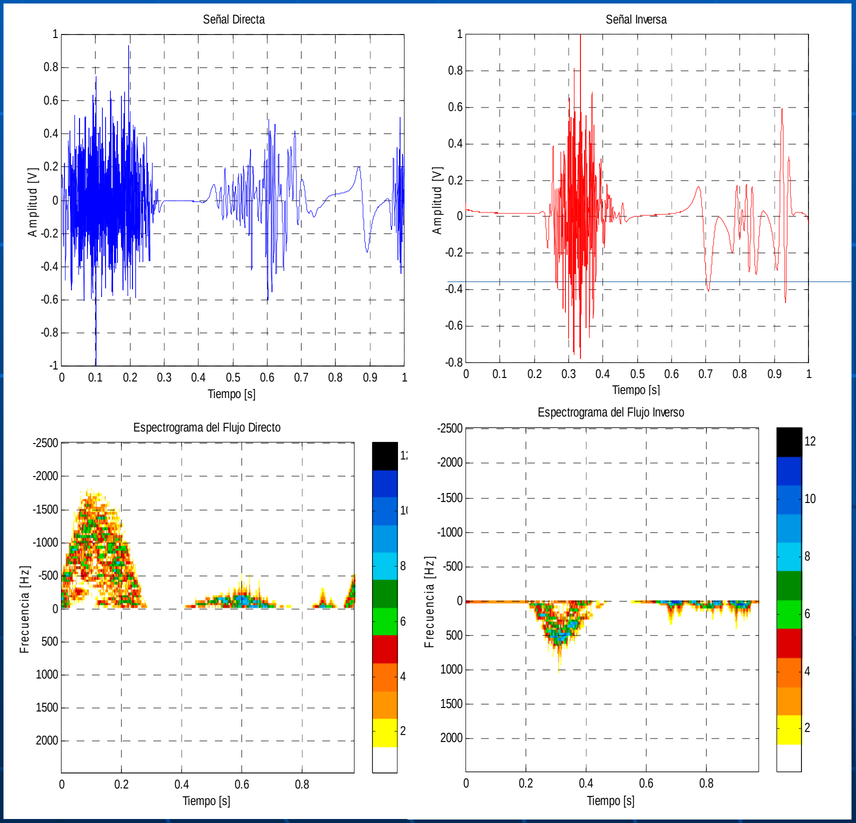


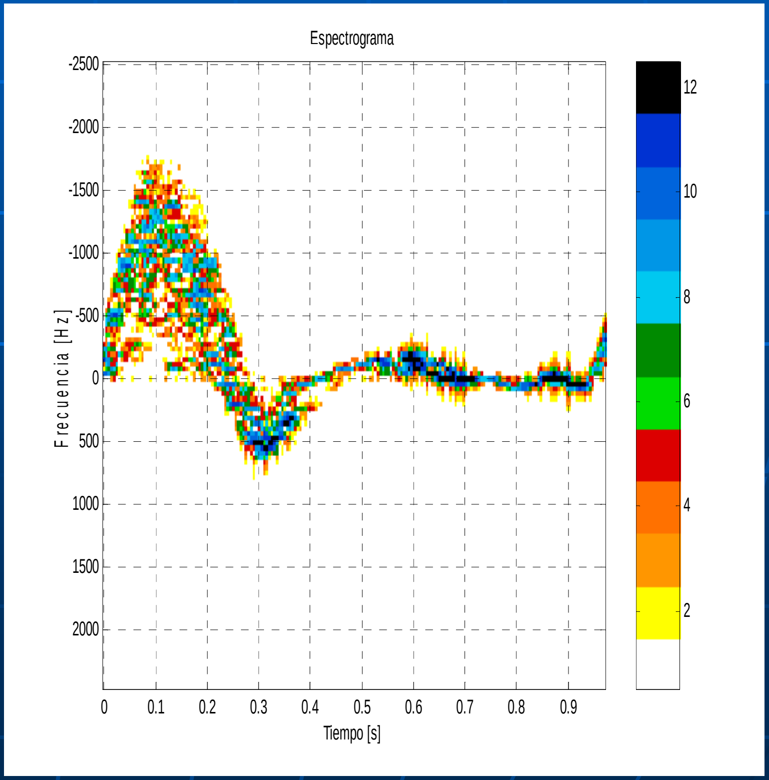




Introduction

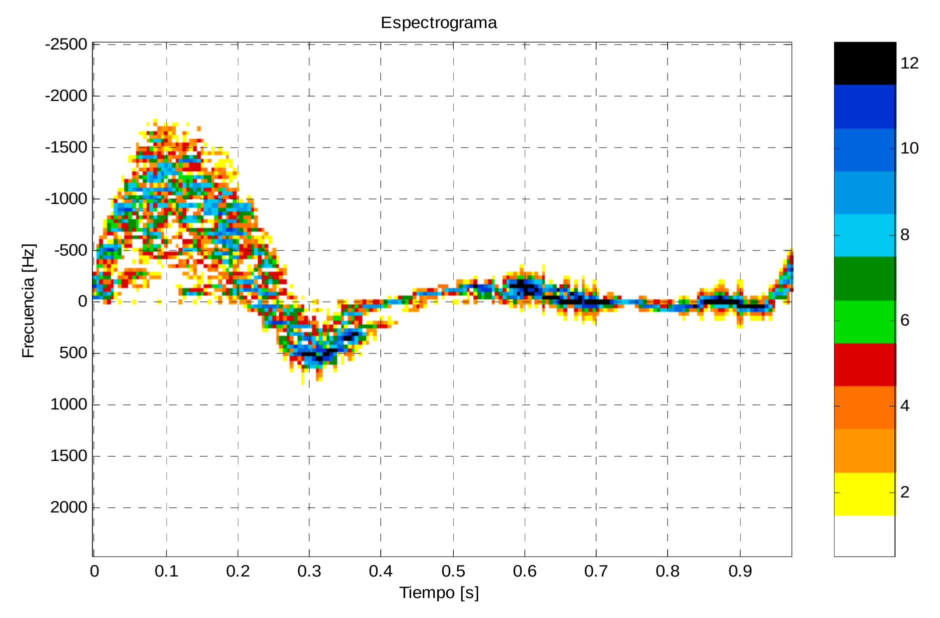
- **Flow direction, signal processing, spectrogram displaying, parameters calculation and a database handling subsystem complete the system.**





Introduction

- A conventional method to determine and display the spectral information is real time spectral analyzer. Signal frequency information is displayed as an amplitude graphic spectral components versus frequency.
- As velocity is periodic, Doppler signal is cycle-stationary and the Doppler spectrum shows variations in the mean frequency and shape along the cardiac cycle.



Introduction

DOPLER SIGNAL PROCESSING

Wigner Ville Distribution

$$WVD\,(t,\omega)=\int_{-\infty}^{\infty} x\left(t+\frac{\tau}{2}\right)x^{*}\left(t-\frac{\tau}{2}\right)e^{-j\omega\tau}\,d\tau$$

$$DWVD\,(n,k)=2\sum_{\tau=-N+1}^{N-1} W(\tau)W^{*}(-\tau)e^{-j\frac{2\pi k\tau}{N}}\bullet$$

$$\bullet\, x(n+\tau)x^{*}(n-\tau)$$

Choi Williams Distribution

$$CWD\,(t,\omega)=\int_{-\infty}^{\infty}\sqrt{\frac{1}{4\pi\tau^{2}/\sigma}}\int_{-\infty}^{\infty} e^{-\frac{(t-\mu)^{2}}{4\tau^{2}/\sigma}}\bullet$$

$$\bullet\, x\left(\mu+\frac{\tau}{2}\right)x^{*}\left(\mu-\frac{\tau}{2}\right)d\mu\, e^{-j\omega\tau}\,d\tau$$

$$DCWD\,(n,k)=2\sum_{\tau=-N+1}^{N-1}\Bigg(W(\tau)W^{*}(-\tau)e^{-j\frac{2\pi k\tau}{N}}\bullet$$

$$\bullet\sum_{\mu=-M}^{M}\sqrt{\frac{1}{4\pi\tau^{2}/\sigma}}e^{-\frac{\mu^{2}}{4\tau^{2}/\sigma}}x(\mu+n+\tau)x^{*}(\mu+n-\tau)\Bigg)$$

Bessel Distribution

$$BD\,(t,\omega)=\int_{-\infty}^{\infty}\frac{2}{\pi\alpha\,|\tau|}\int_{-\infty}^{\infty}\sqrt{1-\left(\frac{t-\mu}{\alpha\tau}\right)^{2}}\,U_{0}\left(\frac{t-\mu}{\alpha\tau}\right)\bullet$$

$$\bullet\, x\left(\mu+\frac{\tau}{2}\right)x^{*}\left(\mu-\frac{\tau}{2}\right)d\mu\, e^{-j\omega\tau}\,d\tau$$

$$DBD\,(n,k)=2\sum_{\tau=-N+1}^{N-1}\Bigg(W(\tau)W^{*}(-\tau)e^{-j\frac{2\pi k\tau}{N}}\bullet$$

$$\bullet\sum_{\mu=-2\alpha|\tau|}^{2\alpha|\tau|}\frac{1}{\pi\alpha\,|\tau|}\sqrt{1-\left(\frac{\mu}{2\alpha\tau}\right)^{2}}\,x(\mu+n+\tau)x^{*}(\mu+n-\tau)\Bigg)$$

Born Jordan Distribution

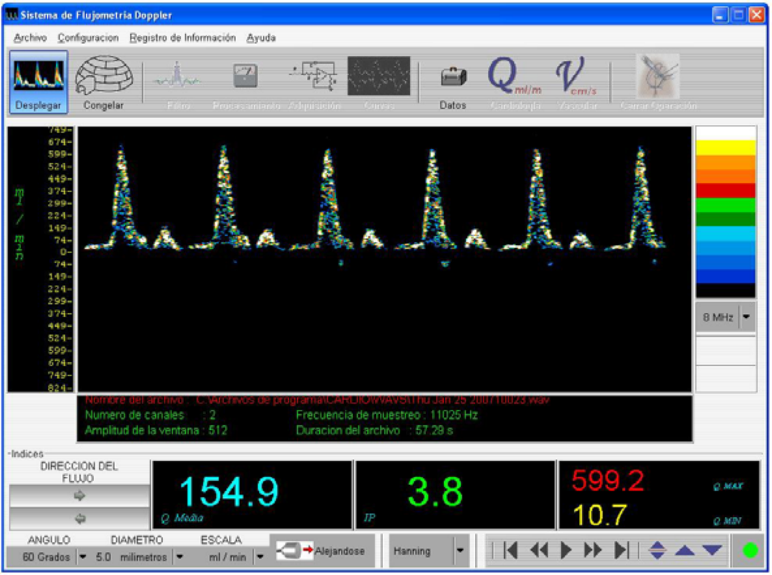
$$BJD\,(t,\omega)=\frac{1}{2\alpha}\int_{-\infty}^{\infty}\frac{1}{\tau}\int_{t-\alpha\tau}^{t+\alpha\tau} x\left(\mu+\frac{\tau}{2}\right)x^{*}\left(\mu-\frac{\tau}{2}\right)d\mu\, e^{-j\omega\tau}\,d\tau$$

$$DBJD\,(n,k)=2\sum_{\tau=-N+1}^{N-1}\Bigg(W(\tau)W^{*}(-\tau)e^{-j\frac{2\pi k\tau}{N}}\bullet$$

$$\bullet\sum_{\mu=-2\alpha|\tau|}^{2\alpha|\tau|}\frac{1}{4\alpha\,|\tau|}\,x(\mu+n+\tau)x^{*}(\mu+n-\tau)\Bigg)$$

Introduction

- **Processing module includes different processing capabilities and calculates automatically the Pulsatility Index, Resistance Index and volumetric flow. The software can also process the Doppler signal using a CFFT (Complex Fast Fourier Transform) algorithm or an AR-Modified Covariance algorithm] to visualize the spectral broadening due to possible stenosis.**



Nombre del archivo : C:\Archivos de programa\CARDIO\WAVS\Thu Jan 25 2007\10023.wav
Numero de canales : 2
Frecuencia de muestreo : 11025 Hz
Amplitud de la ventana : 512
Duracion del archivo : 57.29 s

Q Media 154.9
IP 3.8
Q MAX 599.2
Q MIN 10.7

ANGULO 60 Grados
DIAMETRO 5.0 milimetros
ESCALA ml / min
Alejandose
Hanning

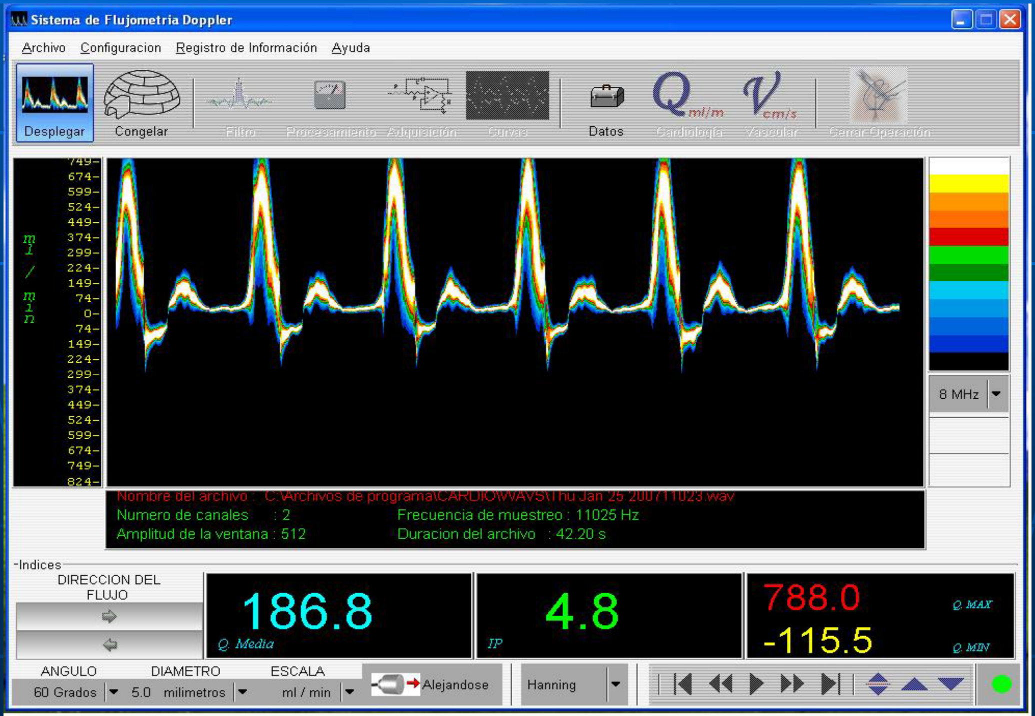
Nombre del archivo : C:\Archivos de programa\CARDIO\WAVS\Thu Jan 25 2007\11023.wav
Numero de canales : 2
Frecuencia de muestreo : 11025 Hz
Amplitud de la ventana : 512
Duracion del archivo : 42.20 s

Q Media 186.8
IP 4.8
Q MAX 788.0
Q MIN -115.5

ANGULO 60 Grados
DIAMETRO 5.0 milimetros
ESCALA ml / min
Alejandose
Hanning

Introduction

- **The Doppler blood flow signal is represented by a spectrogram where the horizontal axis is time [s], the vertical axis is frequency [Hz] or Volumetric Flow [ml/min]. Amplitude is represented with a color proportional to its magnitude.**



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Numero de canales : 2
Frecuencia de muestreo : 11025 Hz
Amplitud de la ventana : 512
Duracion del archivo : 42.20 s

Q. Media: 186.8
IP: 4.8
Q. MAX: 788.0
Q. MIN: -115.5

ANGULO: 60 Grados
DIAMETRO: 5.0 milimetros
ESCALA: ml / min
Hanning

Introduction

- **A graphical user interface is provided for controlling and monitoring the whole system. The software was developed using C++ and Open GL for graphics display.**

Nombre: Martin Fuentes Cruz
Edad: 48
Raza: Mestizo
Fecha nacimiento: 04-04-1959
Sexo: Masculino

Doctor: Dr. Alejandro Villar
Hospital: Hermanos Ameijeiras
Diagnostico:
Notas:
Tipo Bypass: Arteria interventricul
Tipo de vaso: Arteria mamaria izqui
Fecha: 03-07-2007
Hora: 17:50

Nombre: Alian Hernandez Mateo
Fecha de nacimiento: 18-11-1976

Primer Apellido: Hernandez
Segundo Apellido: Mateo
bre: Alian
nto: 18-11-1976
lad: 30
xo: Masculino
aza: Mestizo

ular posterior
e anterior
ginal
erecha
ral

Nombre del archivo : C:\Archivos de programa\CARDIOWAVS\Thu Jan 25 200711023.wav
Numero de canales : 2
Frecuencia de muestreo : 11025 Hz
Amplitud de la ventana : 512
Duracion del archivo : 42.20 s

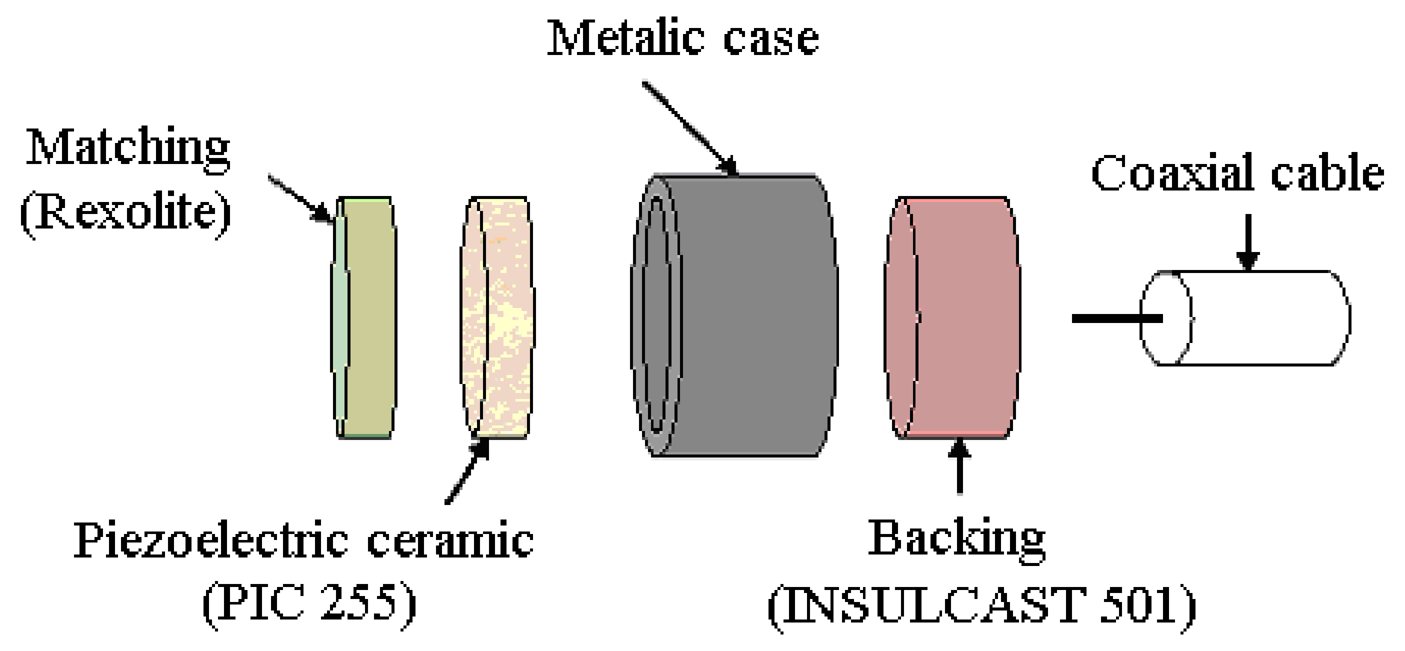
Q. Media 186.8
IP 4.8
Q. MAX 788.0
Q. MIN -115.5

ANGULO 60 Grados
DIAMETRO 5.0 milimetros
ESCALA ml / min

Design and Construction

Using the Finite Element Method (FEM) an 8MHz ultrasonic transducer was simulated and all the components associated were introduced.

COMSOL software was used in the simulation.



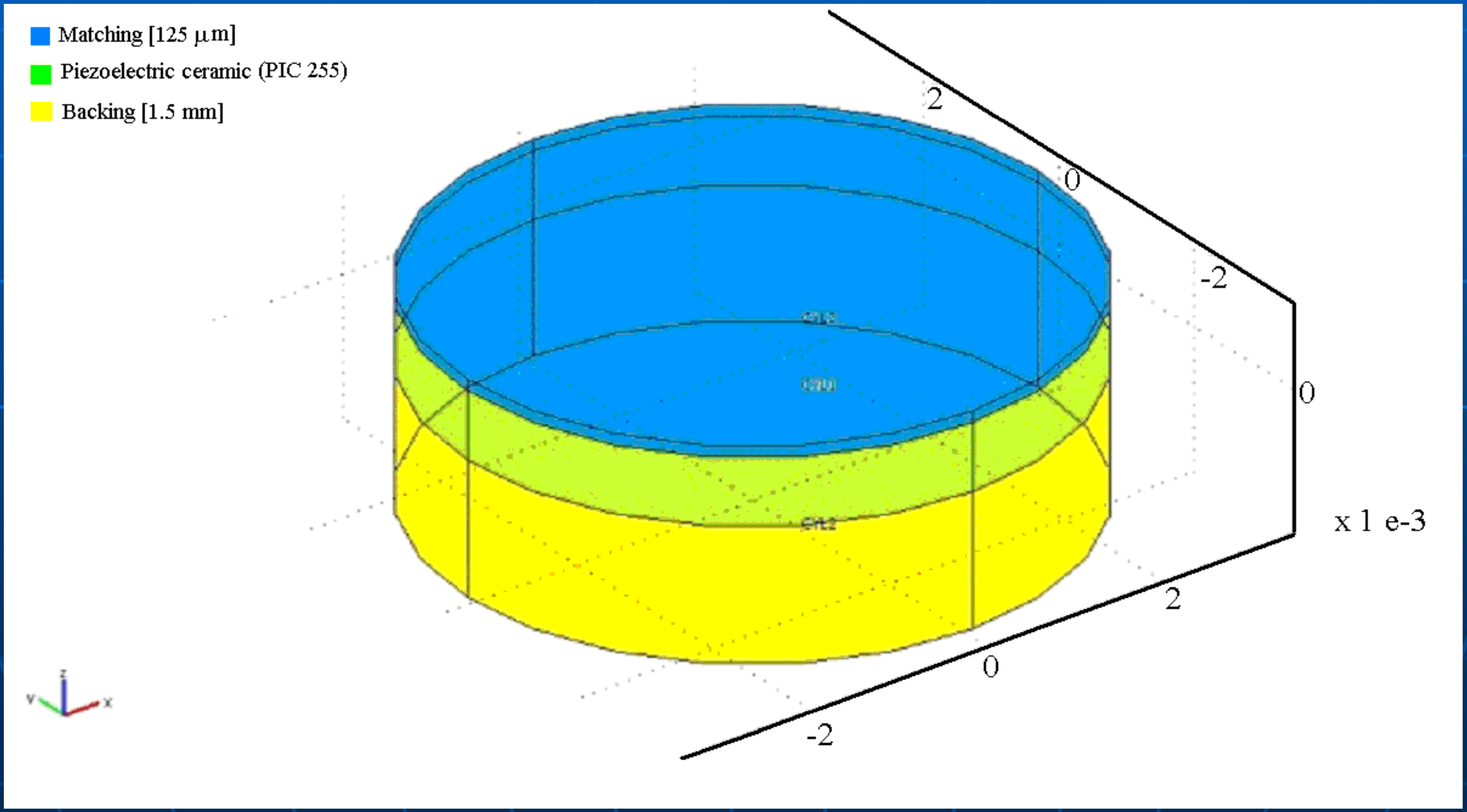
Design and Construction

Physical properties of the parameters used in the COMSOL simulation.

Parameter	Piezoelectric Ceramic	Insulcast 501 (Backing)	Rexolite	Cyanoacrylate
Density	7800 [Kg/m^3]	3860 [Kg/m^3]	1050 [Kg/m^3]	1050 [Kg/m^3]
Young Module	1X10^{11} [N/m^2]	0.19X10^{11} [N/m^2]	31.02X10^{11} [N/m^2]	78.5X10^6 [N/m^2]
Poisson Module	0.34	0.30	0.37	0.34
Thermal Expansion Coefficient	-5x10^{-6}[1/K]	75x10^{-6} [1/K]	70x10^{-6} [1/K]	100x10^{-6} [1/K]

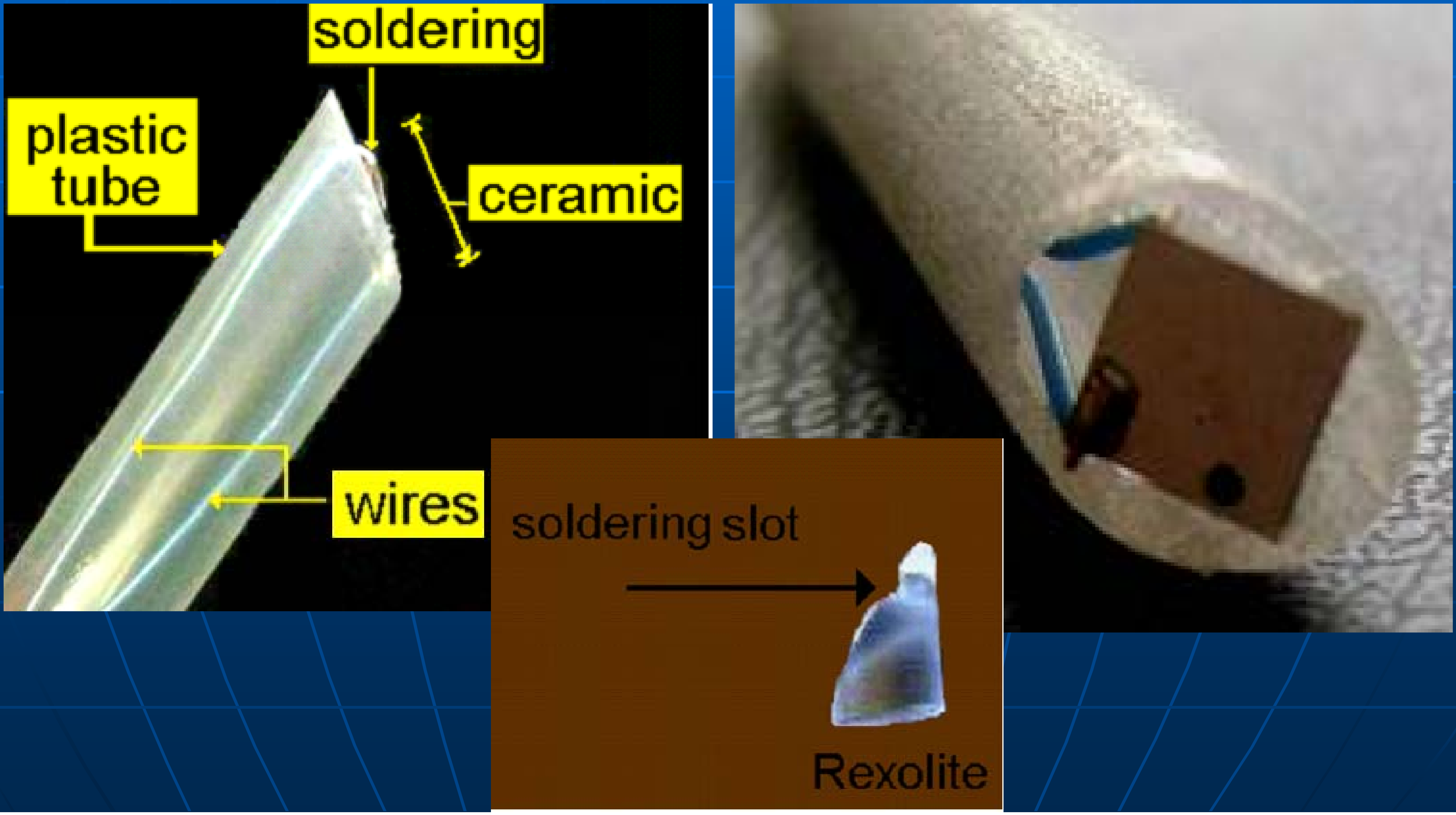
Design and Construction

- **Using the physical properties of the parameters presented in the previous table and COMSOL a simulation was made.**



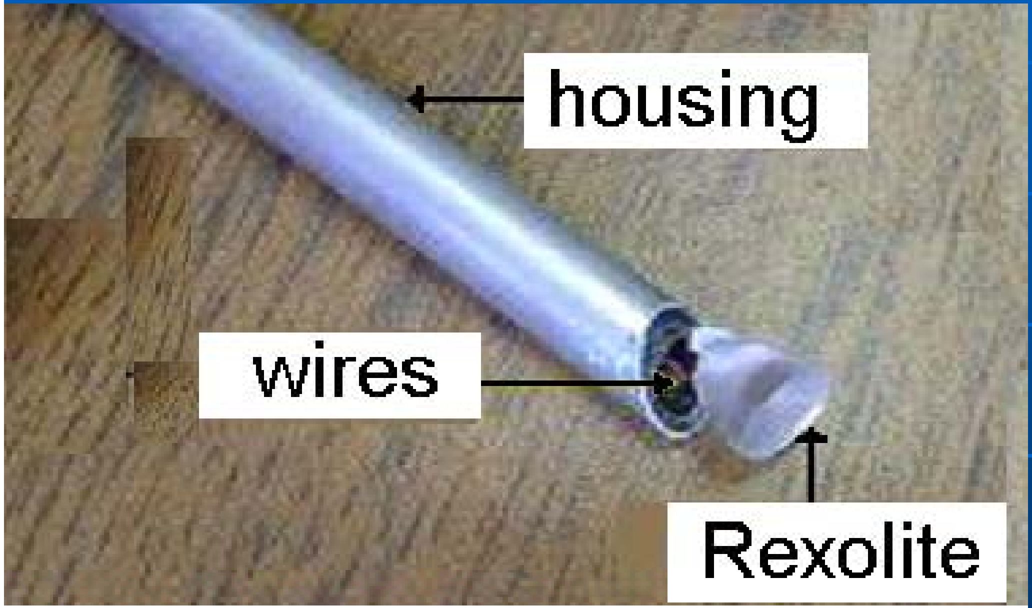
Design and Construction

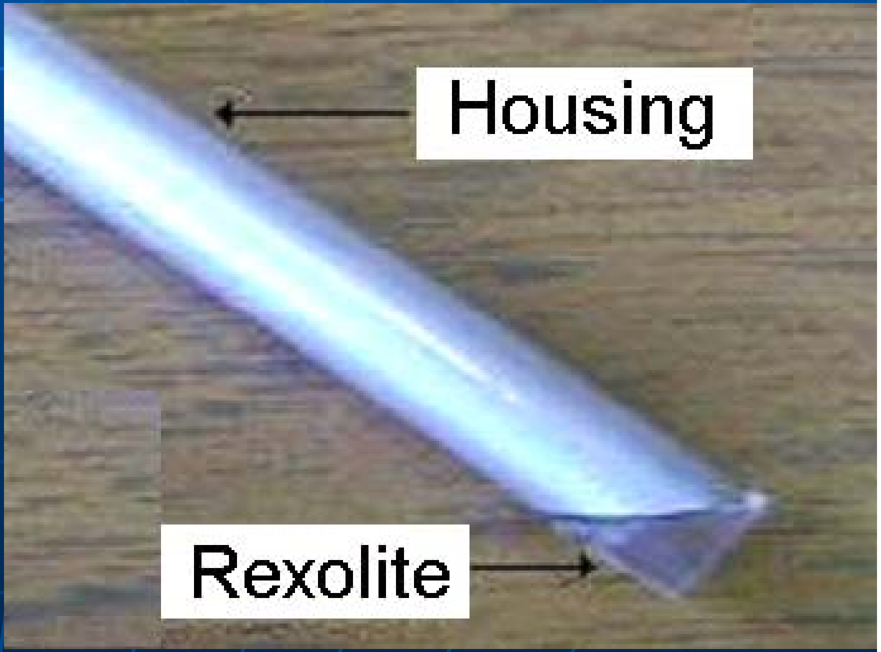
- **Ceramics with electrical connectors, these were glued using cyanoacrylate soldering to the plastic tube.**



Design and Construction

Transducer A with Rexolite (matching element)



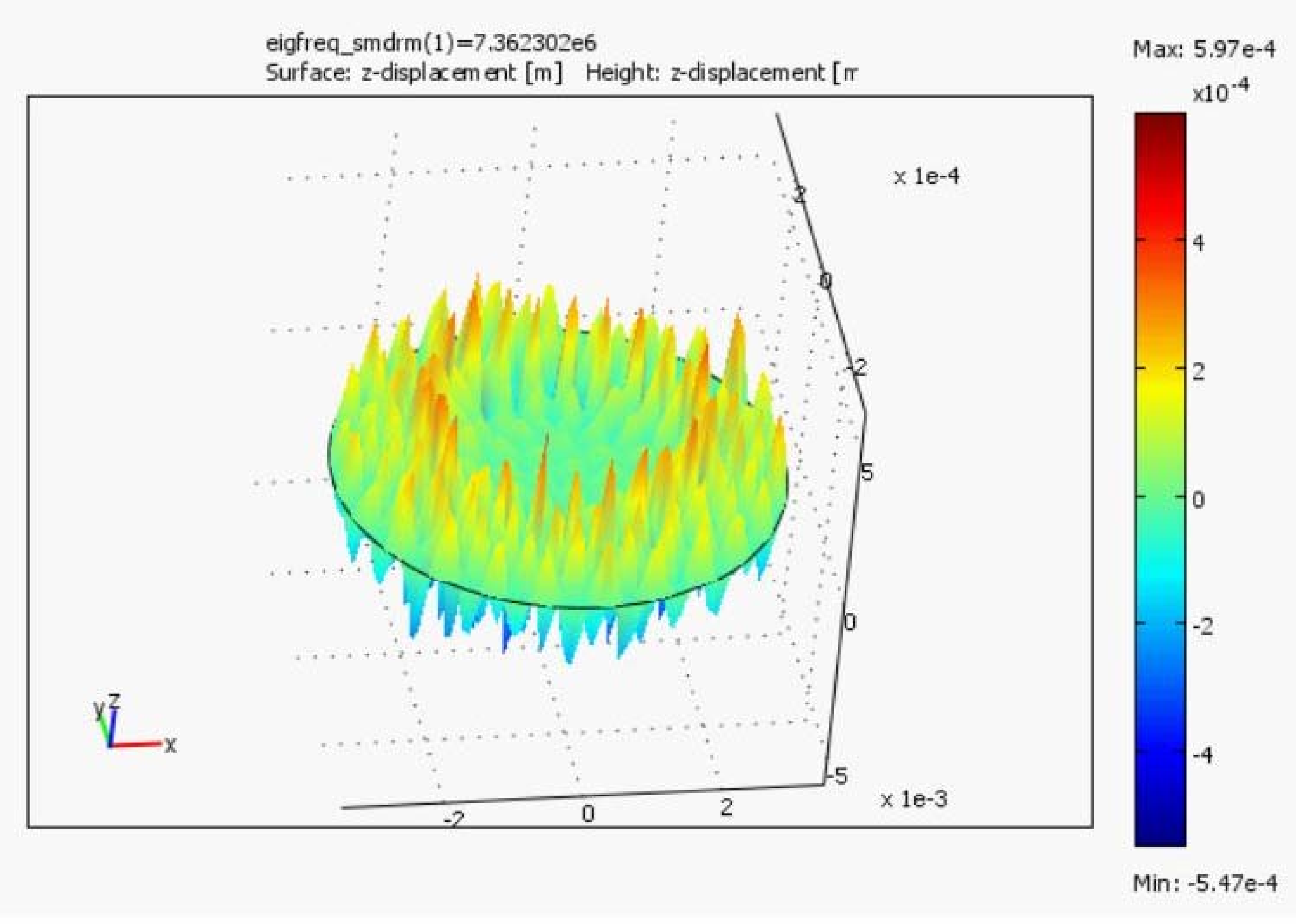


Design and Construction

Transducer B with Rexolite (matching element)

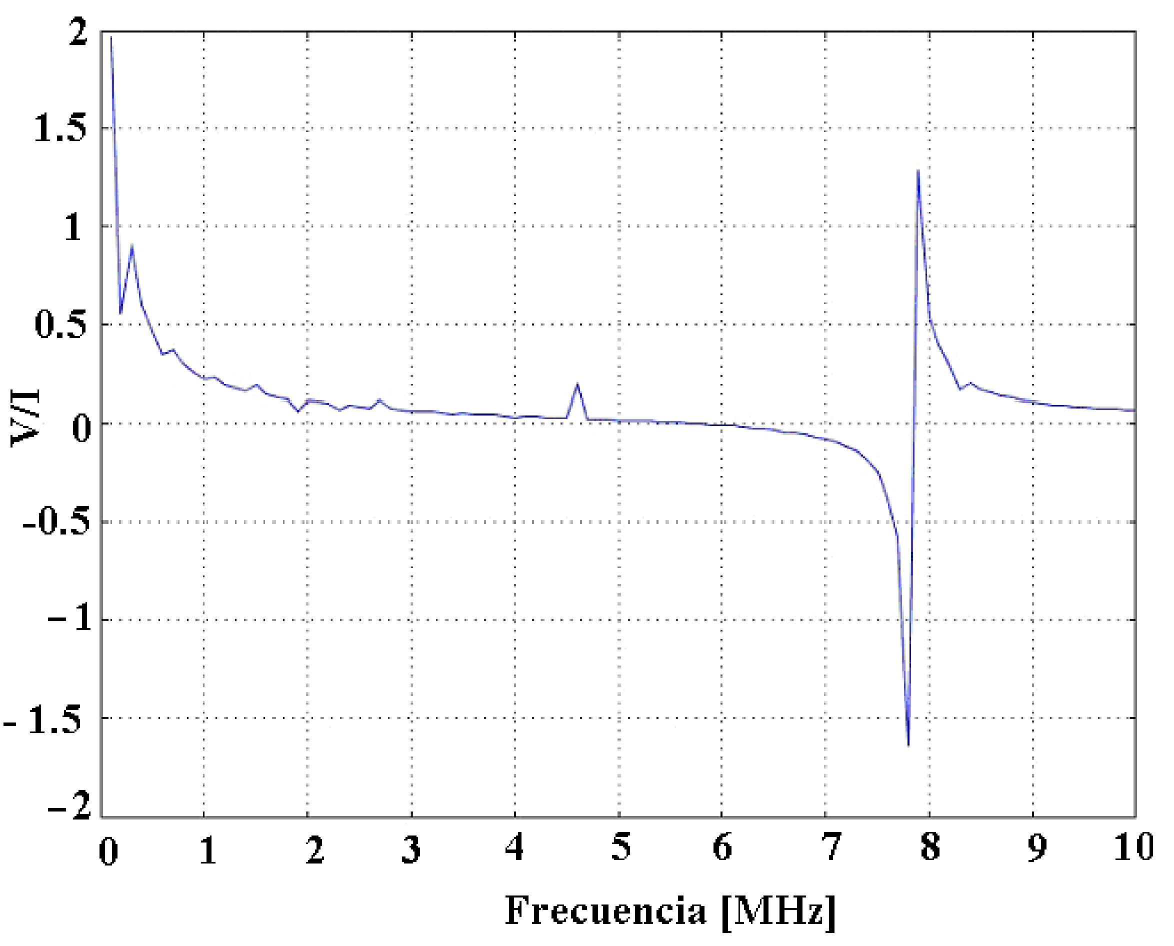
Results

Transducer radiation



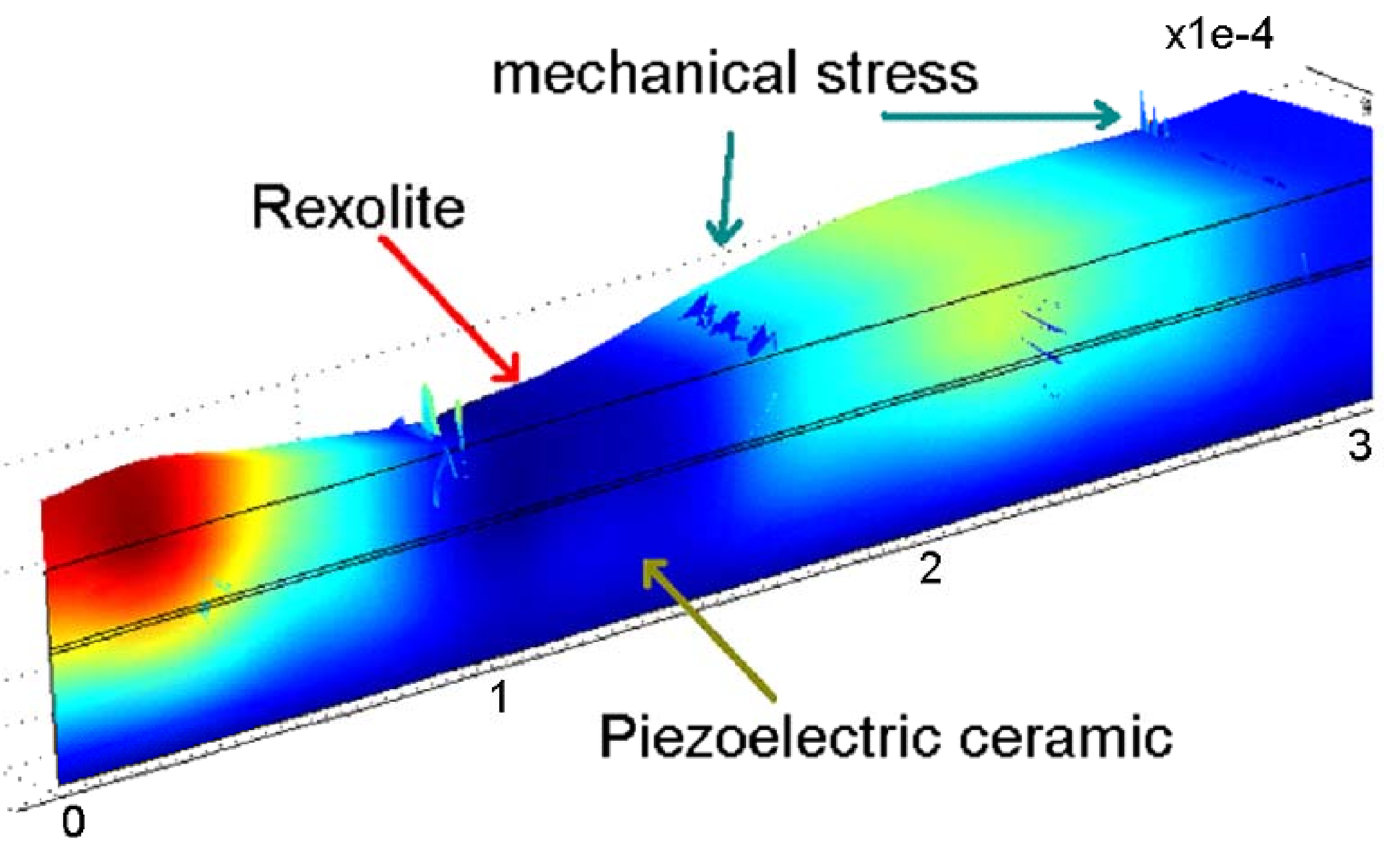
Results

Impedance Plot



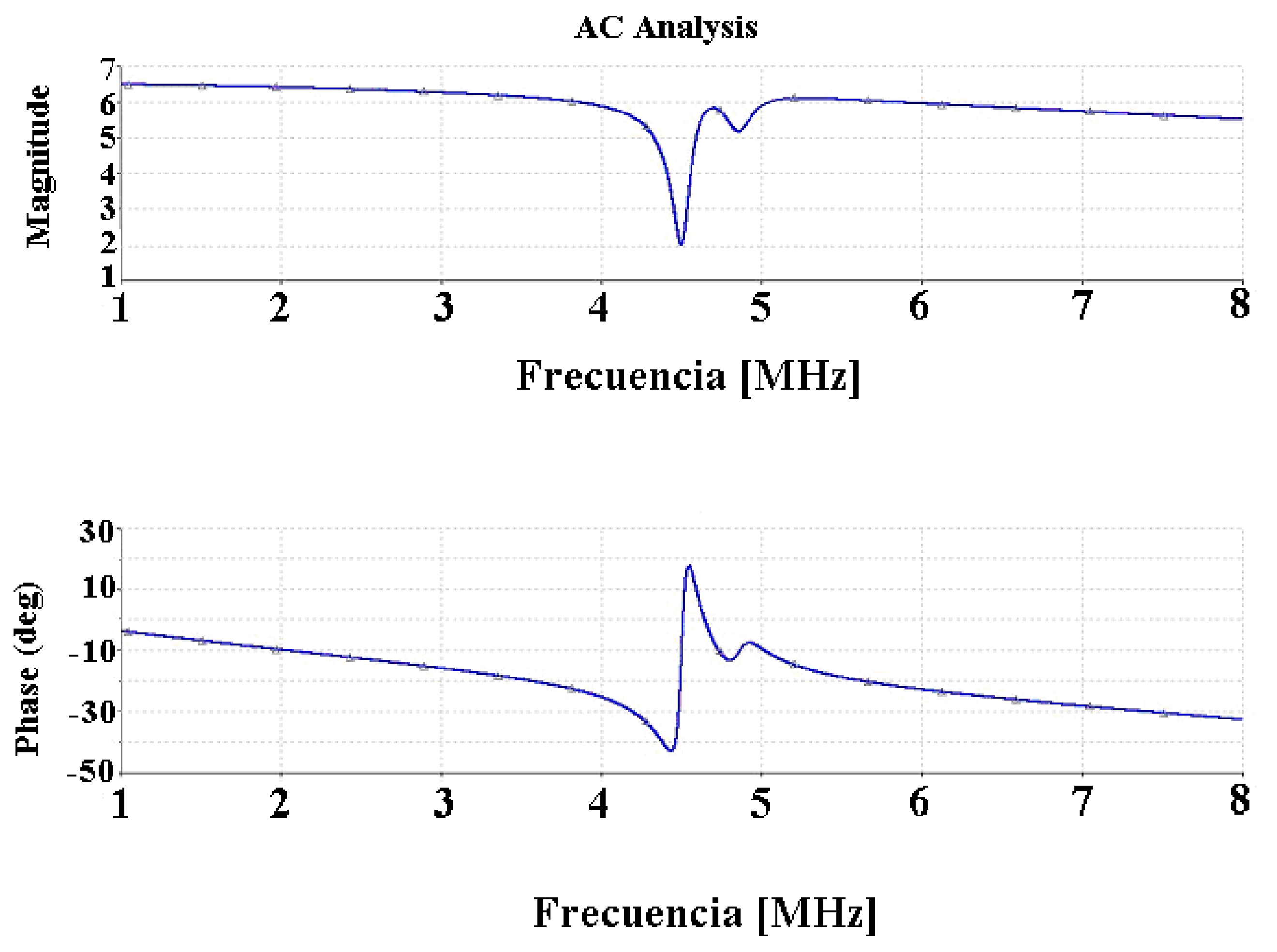
Results

The simulation shows the piezoelectric ceramic and Rexolite vibrating, the vibration mode and mechanical stress are shown.



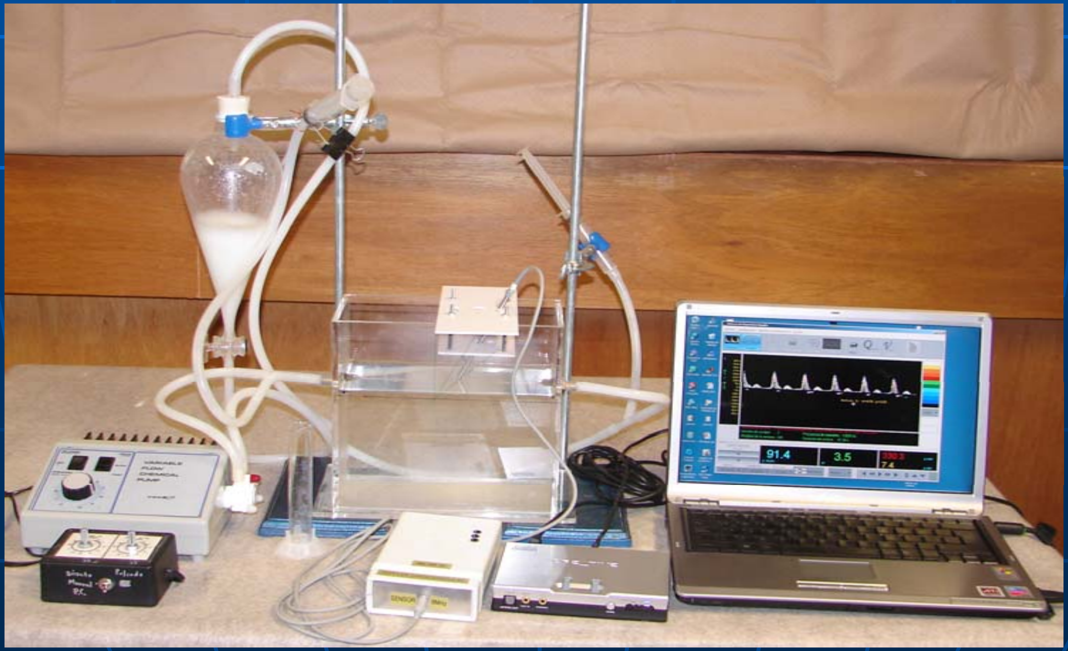
Results

AC analysis shows the resonance frequency at 4.5MHz



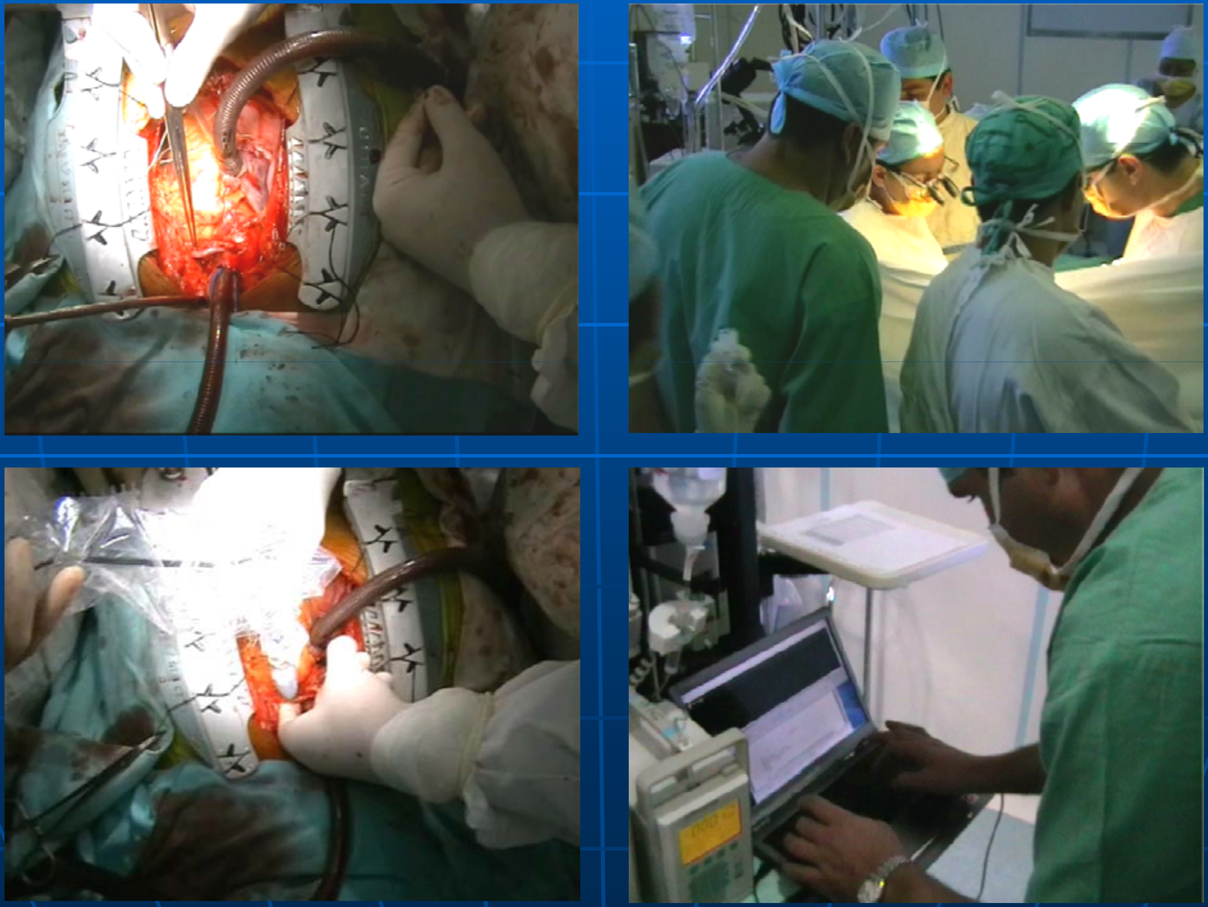
Results

- **Testing of the angled ultrasonic transducer in the laboratory was conducted using a blood flow “phantom” system which includes an electronic controlled pump that emulates different flows and heart rates through 2–4 mm diameter vessels. A mimic blood fluid was used to produce the Doppler effect when passing through the vessels.**



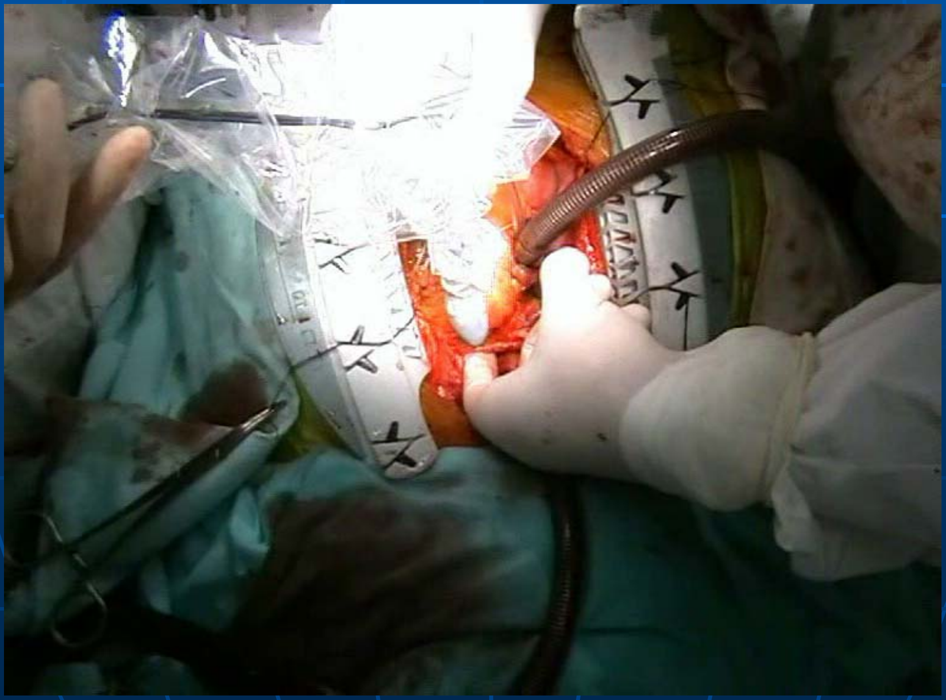
Results

- **The angled ultrasonic transducer has also been tested in real open-heart surgeries in patients that had coronary implanted grafts.**



Results

- **The angled ultrasonic transducer has been tested successfully in the laboratory (with synthetic signals in a “phantom”) and during real surgery, giving important information about the quality of blood flow, providing the cardiovascular surgeon with an suitable tool for detecting anomalies during graft surgery.**



Conclusions

- An angled ultrasonic transducer for measuring blood flow has been presented.
- The angled transducer showed a good performance working with the associated electronics, in both, the laboratory and in vivo tests.
- The performance of the transducer was according with the FEM simulation and the resonance frequency value was 4.5 MHz probably due to bonding problems.
- The angled transducer as an important part of the system is intended to be used in coronary implants and bypasses, aiming to verify the quality of flow in coronary grafts being this essential for the success of a heart surgery.

Conclusions

- Quantifying the blood flow in the implants/bypasses is an important task to ensure the surgical process, thus, reducing both the post-surgical and death risks.
- Both the transducer and the system have been tested successfully in the laboratory and during real surgery, giving important information about the quality of blood flow, providing the surgeon with an suitable tool for detecting anomalies during the coronary graft surgery.
- Further work is being carried out, aiming to provide better angled transducers and software tools that can help in the interpretation of the Doppler grafts signals database.

Aknowledgements

DISCA – IIMAS – UNAM, Mexico

- **Dr. Demetrio Fabián García Nocetti – Project leader**
- **Dr. Julio Solano González - Project leader**
- **Dr. Ernesto Rubio Acosta – Signal Processing**
- **M. Sc. Israel Sánchez Domínguez – Experimental design**
- **Dr. Mónica Vázquez Hernández – Experimental design**
- **Mr. Joel Durán Ortega – Experimental design**
- **Mr. Martín Fuentes Cruz – Electronics**
- **Mr. Alián Hernández Mateo - Programming**
- **Mr. Antonio Contreras Arvizú – Programming**

Hospital Hermanos Amaijeiras, Cuba.

- **Dr. Alejandro Villar - Cardiology**
- **Dr. Juan Prohias - Cardiology**

Thank you

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