DESIGN AND CONSTRUCTION OF A BLOOD FLOW DETECTOR PROBE FOR MEDICAL APPLICATION

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1. Introduction

In medical application, ultrasound is extensively used as a diagnostic tool. There is a wide range of medical instruments which are used in this field from simple fetal phones to very sophisticated imaging systems. The main advantage of ultrasound when applied to diagnostic is that it is non-invasive. In Cardiology, the ultrasonic Doppler detector is a very useful instrument to monitor blood flow, this detector measures the blood velocity in veins and arteries. These measurements provide information about the presence of stenosis and obstruction in arteries. Stenosis is a disease that affects blood flow velocity and pressure producing turbulence, due to this the velocity profile changes modifying the frequency spectrum of the signal, these changes determine the stenosis level.

Blood flow velocity in arteries is periodic in time but its frequency spectrum varies during each cardiac cycle, therefore a blood flow Doppler signal is considered a cycle-stationary stochastic Gaussian signal and in short segments (2-20 ms) is considered a quasi-stationary signal. This signal is commonly analyzed using conventional methods such as the fast Fourier transform and also using spectral estimation parametric methods to obtain a better resolution.

In this paper the design and construction of a Continuous Wave (CW) blood flow detector probe is presented. This device determines the blood velocity, and detects flow disturbance by measuring the Doppler frequency shift of an ultrasound beam scattered from the blood flow, using quadrature phase demodulation. This probe is compact, and includes I,Q quadrature blood flow signal as an output. Total circuit is integrated in 1.5 x 9 cm printed circuit board. This device can operate within 4 to 10 MHz range.

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2. Blood Flow Detector Probe

The simplest blood flow Doppler detector probe is the one described by Sotomura [1]. At present this kind of probes are more compact and efficient, they are used as diagnostic tools in cardiovascular diseases more often.
The basic elements that build the probe are shown in figure 1. This probe is a Continuos Wave (CW) device with coherent demodulation to obtain the blood flow Doppler I (In phase) and Q (in Quadrature) signals.
It is worth to mention that the blood flow Doppler signal is actually formed by two components which are the direct and inverse flow. Therefore it is necessary to have two signals in quadrature Iout and Qout to be able to divide the flow direction, this is achieved using signal digital processing in the frequency domain [8].

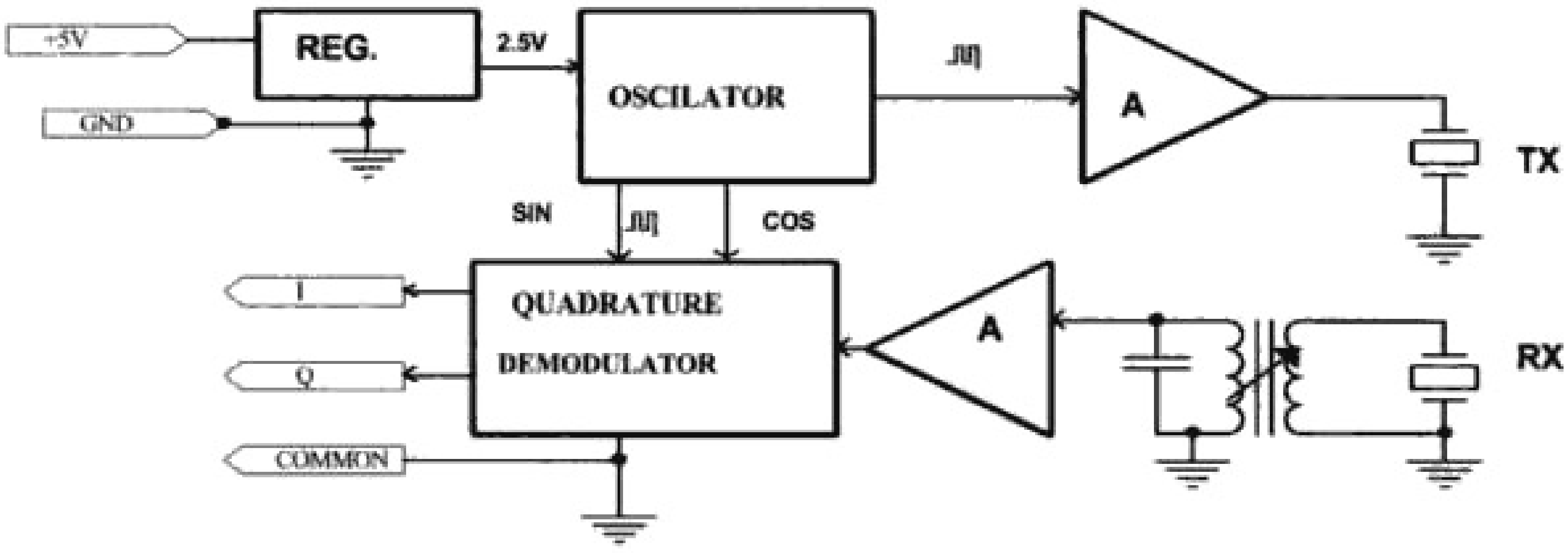

Figure 1. Schematic diagram of the blood flow detector probe.

The transmitter produces an ultrasonic signal that can be defined by the following expression:

$$T(t) = B\cos\omega_0 t \tag{1}$$

where $\omega_0 = 2\pi f_0$ = angular frequency, and f_o = operation frequency of the ultrasonic transducer.

Considering that the ultrasonic signal received *S(t)*, it is formed by the carrier and the two resultant blood flow signals (forward and reverse), it is possible to express it as:

$$S(t) = A_0\cos(\omega_0 t + \phi_0) + A_f\cos(\omega_0 t + \omega_f t + \phi_f) + A_r\cos(\omega_0 t - \omega_r t + \phi_r) \tag{2}$$

where A, ω, y, ϕ are the amplitude, angular frequency and phase of each signal, respectively. *0, f* y r are the carrier, the forward flow signal, and the reverse flow signal, respectively.

With the aim of preserving the real and imaginary components of the Doppler signal, the signal $S(t)$is demodulated in quadrature.

This demodulation consists in multiplying by a signal of the same frequency from the transmitter $\cos\omega_0 t$ and its signal in quadrature $\sin \omega_0 t$.

$$I(t) = S(t)\cos(\omega_0 t)$$

(3)

$$I(t) = \frac{1}{2}A_0[\cos(\phi_0) + \cos(2\omega_0 t + \phi_0)] + \frac{1}{2}A_f[\cos(\omega_f t + \phi_f) + \cos(2\omega_0 t + \omega_f t + \phi_f)]$$
$$+ \frac{1}{2}A_r[\cos(\omega_r t - \phi_r) + \cos(2\omega_0 t + \omega_r t + \phi_r)]$$

(4)

filtering high frequency and eliminating the d.c. components we obtain:

$$I(t)' = \frac{1}{2}A_f \cos(\omega_f t + \phi_f) + \frac{1}{2}A_r \cos(\omega_r t - \phi_r) \tag{5}$$

similarly the signal in quadrature is obtained,

$$Q(t) = S(t)sen(\omega_0 t) \tag{6}$$

$$Q(t)' = -\frac{1}{2}A_f sen(\omega_f t + \phi_f) + \frac{1}{2}A_r sen(\omega_r t - \phi_r) \tag{7}$$

then

$Iout = I(t)'$ is the *In phase* signal and

$Qout = Q(t)'$ is the signal in *quadrature*.

3. Description

In this section a brief description of each one of the elements of the probe is given.

3.1 TRANSDUCER

The transducer used in the design of this probe as it is shown in figure 2, it was constructed using two piezoelectric discs PZT-5 with D form, one working as a transmitter and the other as a receiver. The frequency range depends on the application, for example for fetal phones 2 MHz, for blood flow detection in veins and arteries 4-5 MHz and for detection of blood flow in superficial veins 8-10 MHz.

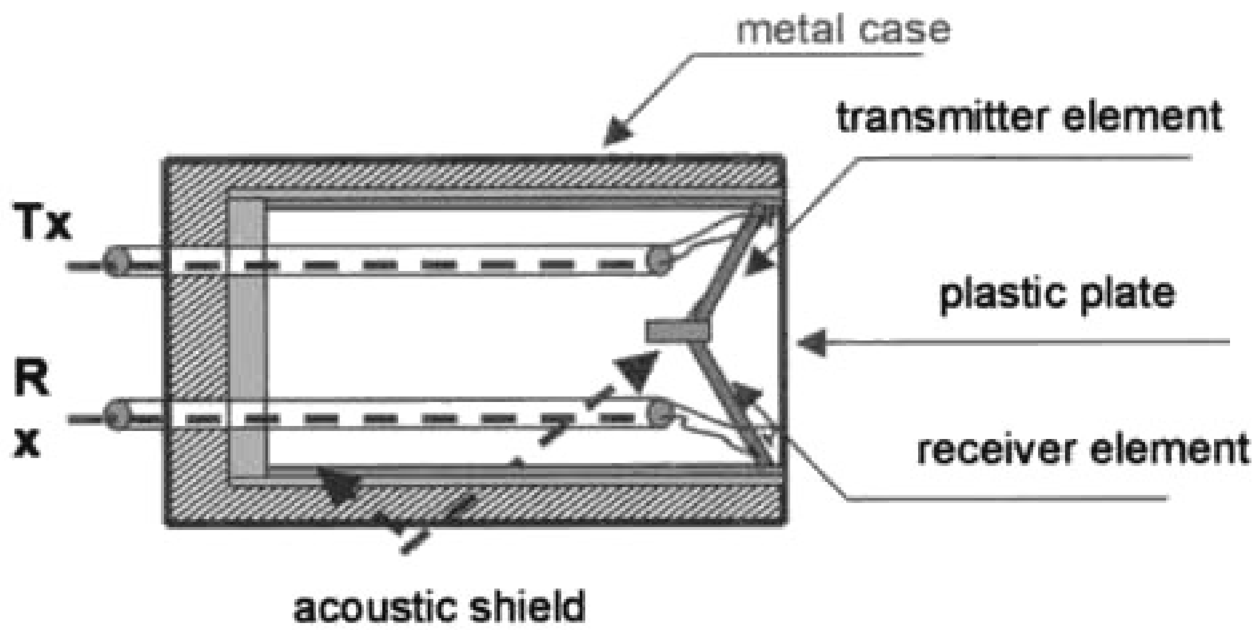

Figure 2. Ultrasonic Transducer

3.2 OSCILATOR-TRANSMITTER

In this stage an ultrasonic continuous wave at the operation frequency is generated (4 ,5, 8 or 10 MHz). Also in this stage the signals in quadrature *Cos* $(\omega_0 t)$ and *Sin* $(\omega_0 t)$ at the same operation frequency of the transducer are generated. Figure 3 shows a schematic diagram of the circuit, it is worth to mention that when designing the transmitter it is convenient to take into account some characteristics such as power and matching impedance and these must fulfill the security levels recommended by the American Institute of Ultrasound in Medicine (AIUM) [2].

3.3 RECEIVER – DEMODULATOR IN QUADRATURE

The recuperated Doppler signal is very small, therefore it is necessary an RF amplification. Figure 4 shows the schematic diagram of this section. It consists of a RF transformer tuned to the operation frequency of the ultrasonic transducer, a FET transistor used as an RF amplifier in cascade configuration with two bipolar transistors which function is to mix the received signal with the signal in quadrature *Cos* $(\omega_0 t)$ and *Sen*$(\omega_0 t)$, advantage is taken of the RC components to limit the frequencies forming a low-pass filter cutting the high frequencies (equation 4) leaving alone the blood flow Doppler signal. Two miniature trimmers are included in this section to balance *Iout* and *Qout*, compensating small errors due to the variation of the electronic components.

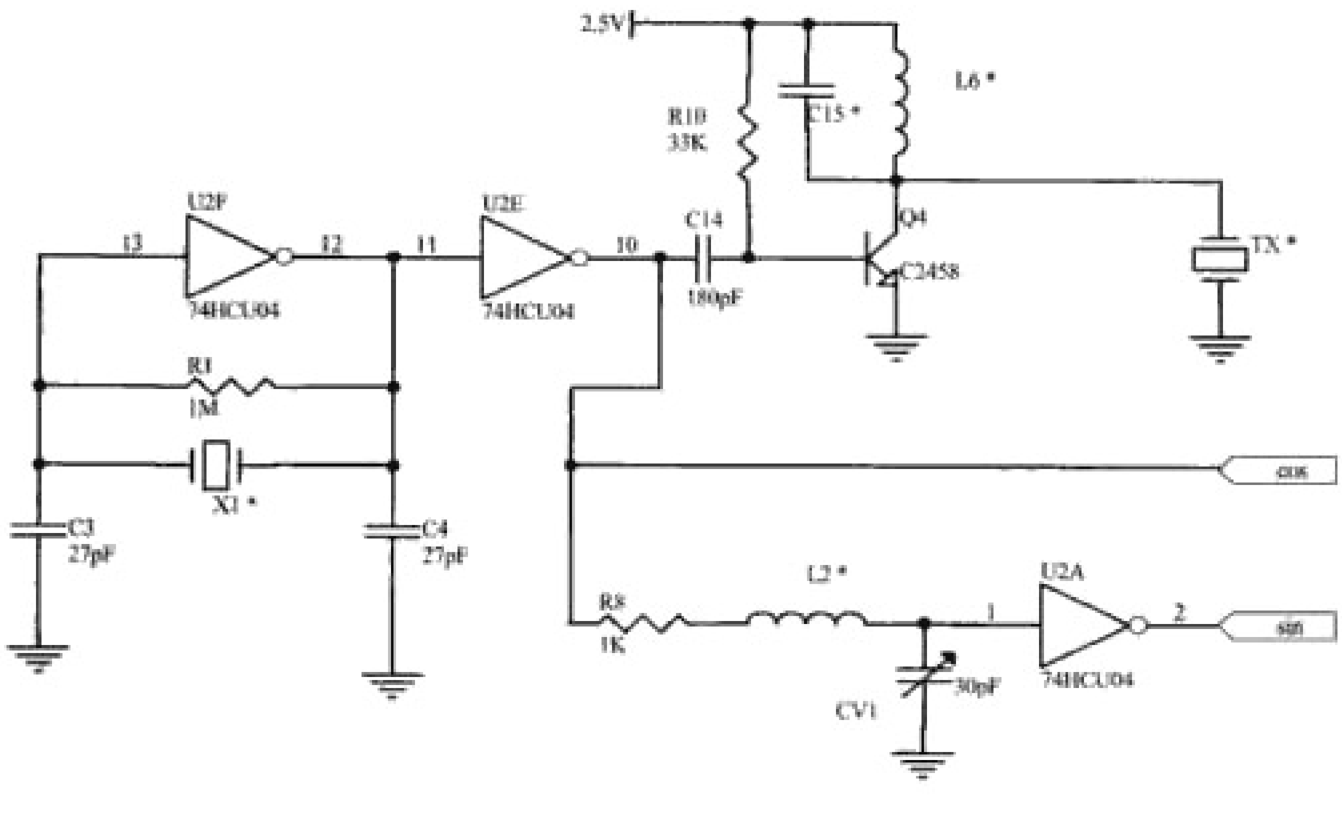

Figure 3. Schematic Diagram of the Oscilator- transmitter. Components marked with an * are dependant on the frequency operation of the ultrasonic transducer

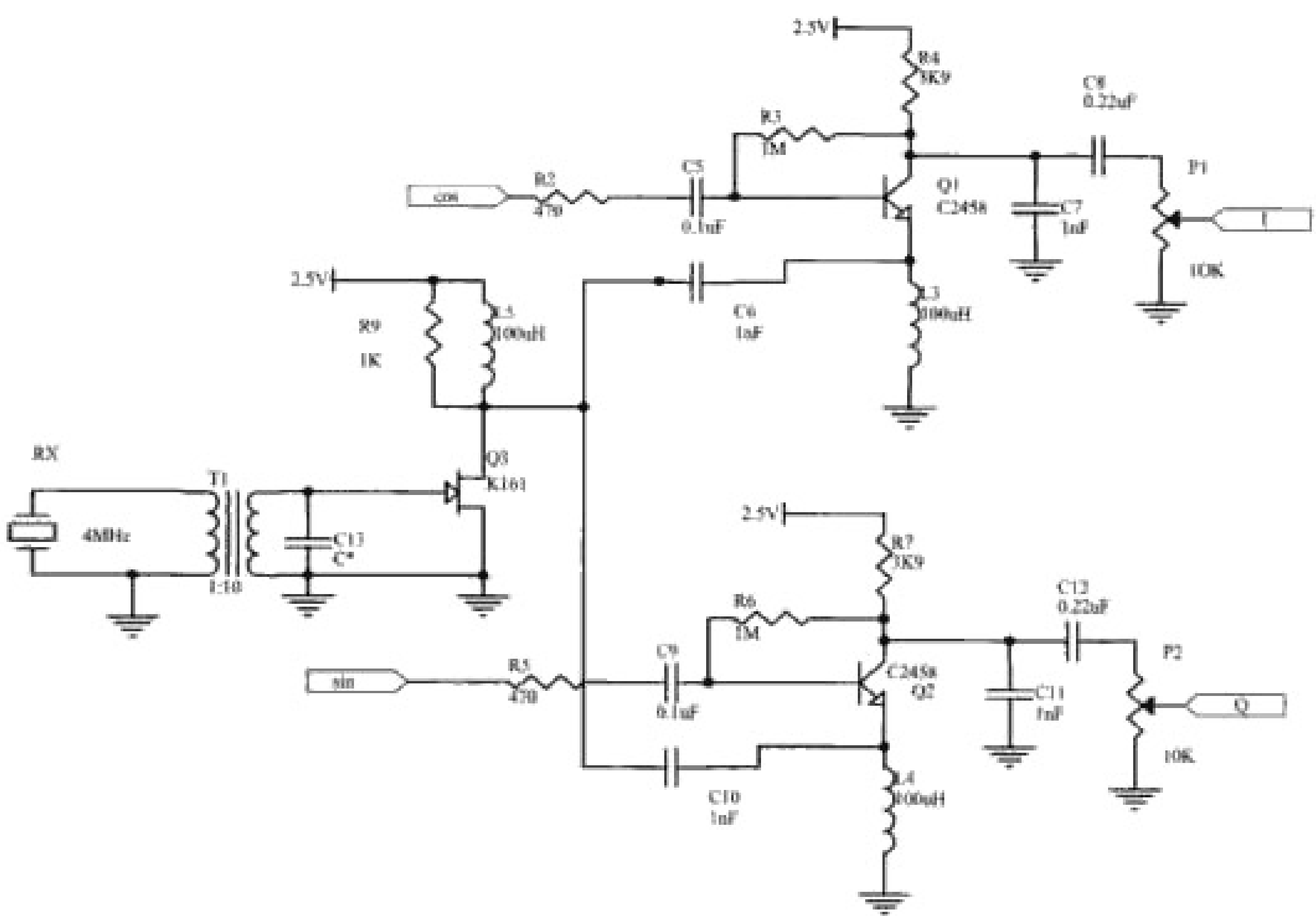

Figure 4. Schematic Diagram of the Receiver-Demodulator in Quadrature. Components marked with an *,must be tunned up at the ultrasonic transducer's frequency.

If we consider that the human blood flow velocity profile has a range of 20-700 mm/s, and the ultrasonic velocity in tissue is about 1540-1600 m/s [2] [6] [7], using ultrasonic transducers within 2-10 MHz we are able to estimate the range of the recovered blood flow Doppler signal.

The Doppler signal is given by:

$$Fd = (2v/c)\,fo \quad (8)$$

So the blood flow Doppler signal lies within 200-10,000Hz, that is the audible range and it is relatively easy to divide the high frequencies from the signal of the detector.

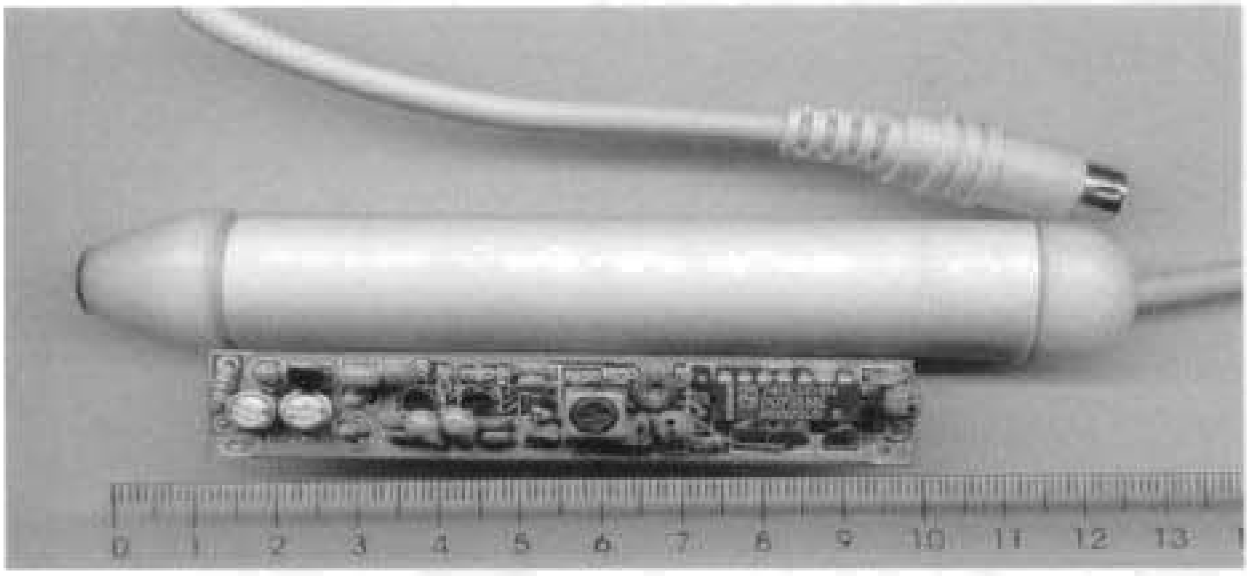

Figure 5. Detector probe with printed circuit board, ultrasonic transducer (probe), PVC container and connector cable (scale is in cm).

4. Experiments and Results

To verify the performance of the probe the I and Q outputs were connected to an amplifier and filter of two channels. The filters used were fifth order band-pass filters with a cut frequency of 300 and 8000 Hz and an amplification of 40-50 dB per channel.

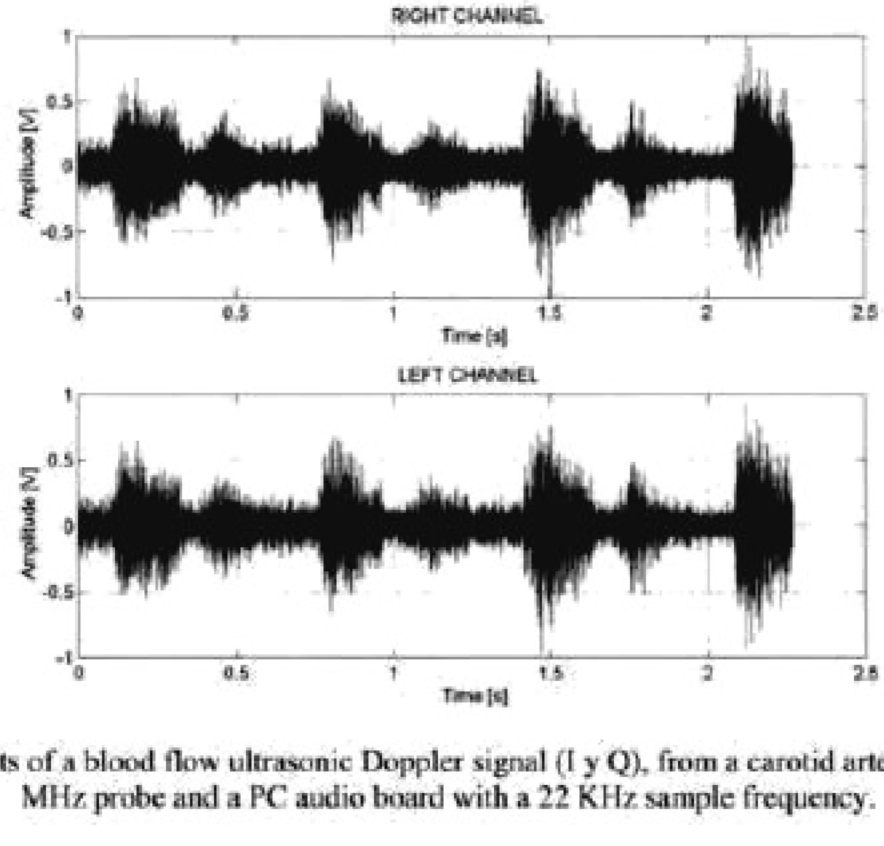

Figure 6. Segments of a blood flow ultrasonic Doppler signal (I y Q), from a carotid artery acquired using 4 MHz probe and a PC audio board with a 22 KHz sample frequency.

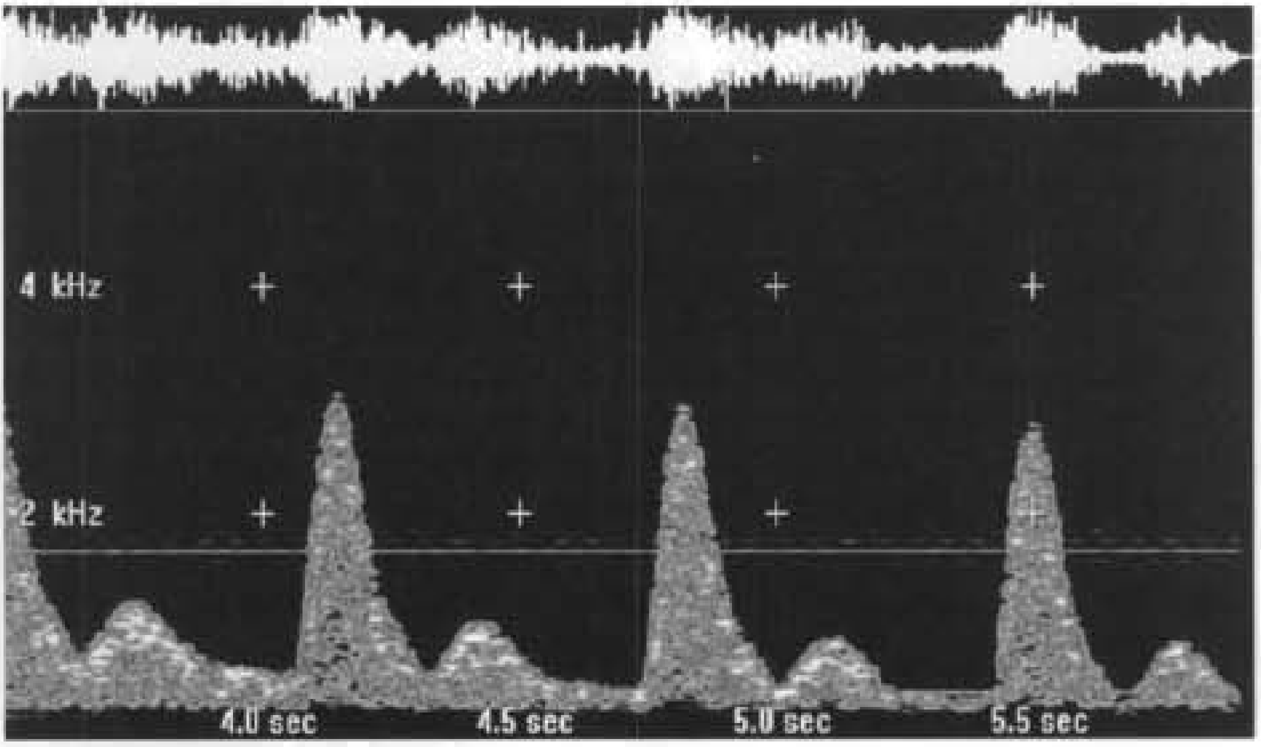

Figure 7. Spectrogram of one of the signals in figure 6. A method based on the Short Time Fourier Transform (STFT) with a 512 point sampling window was used.

These filters and the probe were designed and constructed as an integral section of a bi-directional blood flow Doppler system at DISCA-IIMAS-UNAM laboratory.

Using MATLAB 6.1 tools, I, Q blood flow signals coming from the probe were acquired using a PC Pentium III audio board, these signals were stored as WAV files. Figure 6 shows these signals.

To verify the frequency spectrum of the acquired signals I, Q an specific software was developed to display the spectogram of the blood flow signal as shown in figure 7.

5. Conclusions

The blood flow Doppler detector probe has a good performance, having the transmitter and receiver at a short distance from the piezoelectric discs and also having a good shield gives to the probe good sensibility and low noise. The design of the circuit allows the probe to operate within a range of 4 to 10 MHz depending on the depth of the blood flow detection in veins and superficial blood vessels. Validation of the performance of the probe has been made acquiring real signals associated to the blood flow in arteries, and also processing and displaying these signals as spectograms. Comparison of these spectograms with spectograms produced with commercial equipment has shown the good performance of the detector probe.

6. Acknowledgements

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