Sensor Conditioning for
Ultrasonic Remote Sensing Immersion

Sylvie Breton[1*], Mohamed Benbouzid[2]

University of Brest, EA 4325 LBMS, Rue de Kergoat, CS 93837, 29238 Brest Cedex 03, France
[*1]Sylvie.Breton@univ-brest.fr, [2]Mohamed.Benbouzid@univ-brest.fr

***Abstract-* Ultrasonic detection has many applications in military, medical, marine biology, and physics domains. This paper presents then an emitting signal design for several immersion applications such as liquid level measurement, wall detection for submarine robots, and fish species behavior study. The designed and realized circuits are very simple, of flexible use, and cost-effective. Sensor sealing problems are also discussed in this paper.**

Keywords- Ultrasonic Sensing Target; Immersion; Sealing; Packaging

I. INTRODUCTION

The main applications of ultrasound wave detection are medical, military, and civil such as marine biology or physics. After a brief reviewing of ultrasonic detection applications, we detail the emitter signal conception in two important applications: a wall detection method for water-level measurements or to guide an underwater robot, and the coded signal used for emitters in fishes to follow their movement during the reproduction period and distinguish the species present.

II. ULTRASONIC DETECTION APPLICATIONS

Ultrasound is used for their propagation in media. Many applications exploit the properties of ultrasound, namely:

- the Non-Destructive Testing (NDT) or ultrasound medical ultrasound (prenatal ultrasound, Doppler ultrasound) [1]
- the transmission of information in marine biology (underwater acoustics) [2]
- the distance measuring equipment (telemetry) [3]

Many publications explore the possibilities for applications in control for many types of food, chemical analysis [4]

- assessing the percentage of oil in an emulsion with a speed measurement
- measure of the percentage of sugar in fruit juices by measuring speed

In the case of low power signal, the most applications are non-destructive testing NDT(defect detecting systems) [6] [7] or telemetry. In the military underwater acoustics applications, the objective is to detect mines or submarines. Two systems exist: active sonar which sends a signal and detects echoes returned by targets, and passive one which is listening all the signals sent by targets.

The marine biology usually uses active sonar which signal echoes on fishes bands. This allows following their movement for fishermen but the species fish identification is not easy for their behavior study (environment and reproduction)[2]. More recently [5], emitting sensors are placed in fishes stomach, each with a specific code for the species under study, and a passive sonar is listening in a wide ultrasound band 32-300kHz.

We present here an electronic emitting circuit which allows two types of applications : underwater telemetry and fishes species tracking, thanks to its great flexibility

III. SENSORS USED FOR TELEDETECTION APPLICATION

The transducers are composed of a disk of piezoelectric crystal (in our experience: ceramic) cut perpendicular to a favorable orientation undergoing changes following its thickness (cf Figure 1). The fluctuations are about a few microns.
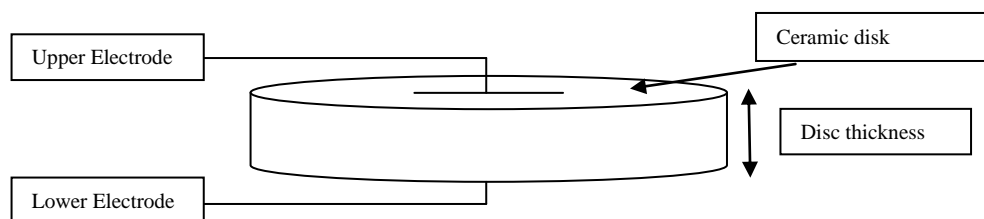

Fig. 1 Disc piezoelectric crystal

The phenomenon of piezoelectricity backs to the Curie brothers in 1880. They observed an action on a quartz cut in a particular direction where would produce such an electrical bias within the material (direct piezoelectric effect). Lippmann discovered reverse phenomenon, the application of an electric field which leads to an expansion or contraction of the material in the axis of the field. This has been generalized to other materials.The transmitter and receiver operate in parallel because of the reversibility of the transducer, the transmitter transforms the electrical signal into mechanical wave and on the receiver, the reverse phenomenon happens. Both may work at the same frequency. The choice of this frequency depends on the distance to be travelled and on the target's size. Indeed, the signal's wavelength varies from 1,5mm at 1MHz under water to 1,5m at 1kHz. The size of the tranducer will also decrease with frequency while the resolution increases and this property could also be significant according to the application.

For telemetry application, the emitter uses a *ping* signal, which is a pulse modulating the exciting signal of the sensor. The choice of the exciting frequency depends on the resolution needed, and the pulse width depends on the propagation medium.. The ultrasound wave velocity is about 330 m.s^{-1} in air and 1500 m.s^{-1} in sea water. This corresponds to a wavelength of 8.25 mm in air and 37.5 mm in sea water at the frequency of 40 kHz. The attenuation coefficient is about 0.0022 dB/MHz.cm in water [8], so 8.8 10^{-3} dB/m at 40 kHz, and about 0.01 dB/kHz.ft in air [9], so 0.122 dB/m at this frequency, thus more than 10 times greater.

We choose the frequency value of 40kHz for our application because it is a standard value used for tranducers (then effective cost), and we don't need a resolution below few centimeters for our purpose. The tranducer choosen are Murata MA40E7S for sender and MA40E7R for receiver, both are encapsulated in waterproof capsules, but it is necessary to conceive a waterproof system to electrically condition the sensors. This has been carried out with the system presented below [11]

TABLE I LEGEND OF SENSORS ASSEMBLY ON FIGURE 2

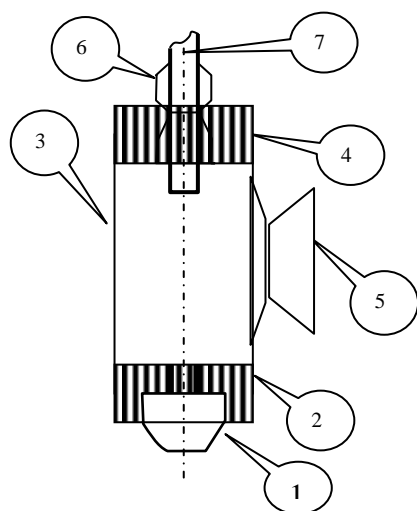|	
1	transducer
2	Cap D32 mm drilling 18 mm
3	Muff D32 mm
4	Cap D32 mm drilling 12 mm
5	Sucker
6	Gland
7	Signal cables

Fig. 2 Sensors assembly.

First test on a prototype at a depth up to 30 cm showed the perfect sealing of the system for 24 h.

IV. SENDING SIGNALS IMPLEMENTATION

The *ping* signal is a pulse modulating the signal oscillating at the frequency at which the sensors are sensitive (see Fig. 3). The sensors used run at 40 kHz. Vcc can be chosen between 5V and 15V, depending on available battery's.
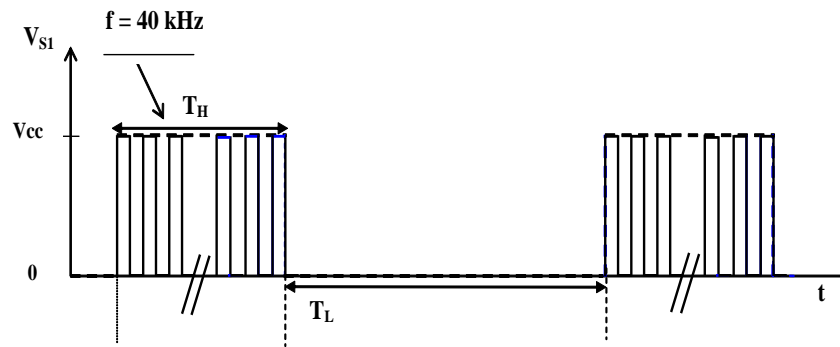
Fig. 3 *Ping* Signal

A. *Oscillator*

The fundamental signal were carried on from a CMOS quadruple NAND circuit 4011 (see Fig. 4), a classical setup inspired by [10]. The oscillating period was measured for different values of R_4 and Vcc, with $C_4 = 1nF$ (see Fig.5). Using 15 kΩ value for the potentiometer will allow to get 40 kHz for Vcc = 12V (standard battery supply voltage).
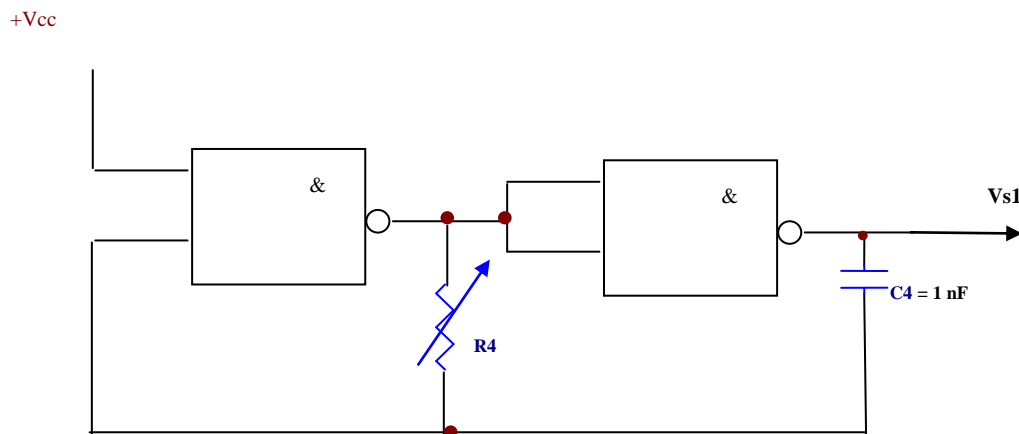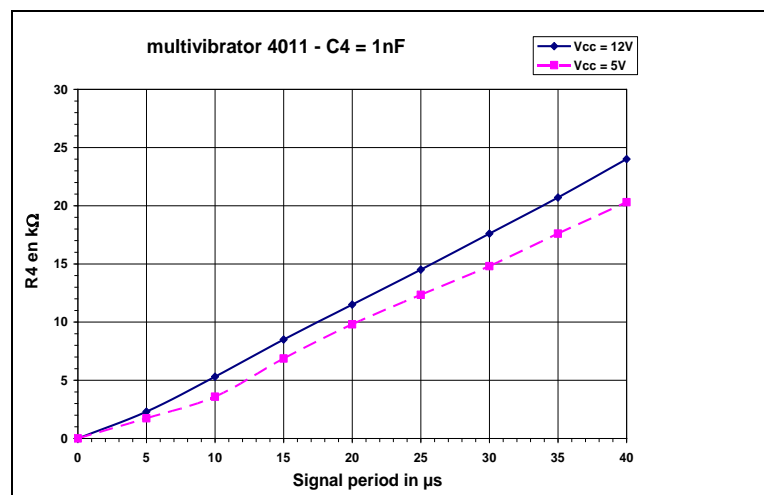

Fig. 4 The 40 kHz Oscillator

Fig. 5 R4 value against signal period

B. *Modulating Signal for a Telemetry Application in Air Media*

The pulses signals were carried on from a NE555 timer in astable configuration [12] (see Fig. 6). The principle of the NE555 is based on an assembly with two thresholds trigger inverter Vcc/3 2Vcc/3. The operation uses the charging and discharging of the capacitor.
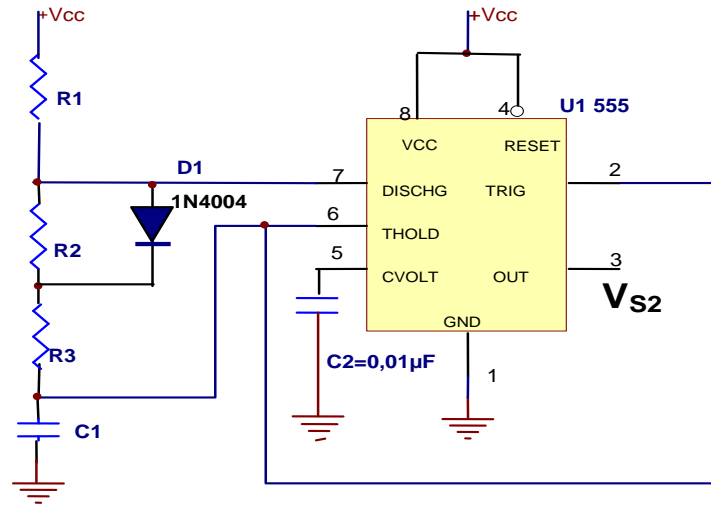
Fig. 6 NE555 timer in astable configuration [12].

Diode D1 allows a duty cycle less than 0,5. TRIG grows exponentially with time constant $(R_1 + R_3) C_1$. The diode D1 is conductive, OUT = Vcc. TRIG then decreases with time constant $(R_2 + R_3) C_1$. The diode D1 is blocked, OUT = 0. The choice of components should be such that:

$$T_H = 0{,}693 \cdot \left(R_1 + R_3 \right) \cdot C_1$$

$$T_L = 0{,}693 \cdot \left(R_2 + R_3 \right) \cdot C_1$$

For telemetry applications in air media, such as water level measurement above the surface, the modulating signal must have $T_H = 1$ms to contain several periods of the 40 kHz oscillator, and $T_L = 0{,}5$s to avoid overlapping between emitted and received signal, this value corresponds to 165m distance travelled by the ping signal. The resistances must be greater than 1κΩ to keep power dissipation under ¼ W. So we choose $R_1 = 3{,}9$ kΩ, we will therefore take $R_3 = 10$ kΩ if C_1 is set to 0.1μF As a result, we will take $R_2 = 720$kΩ.

The modulation is the logic product (AND function) between vs1 and vs2, and is then carried on with the 2 last NAND gates of the 4011 quadruple NAND circuit. The final setup is shown in Fig. 7.
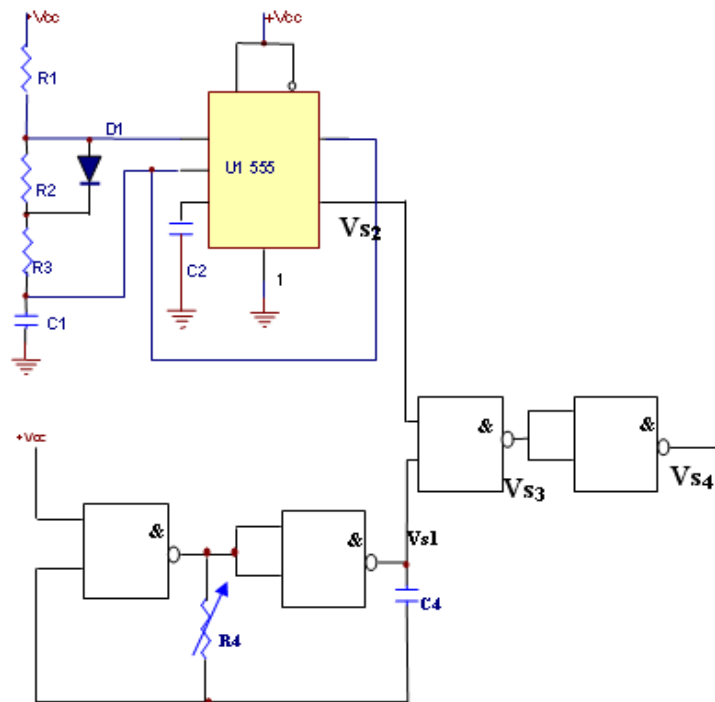

Fig. 7 Telemetry sender assembly diagram

The amplitude of the received signal for propagation in air is very low, it is necessary to amplify about 500 times. For this we use an operational amplifier 741 mounted type non-inverter (See Fig. 8). For underwater application, an amplification of 200 times is sufficient.
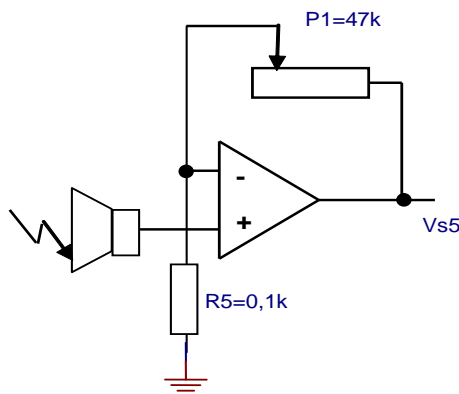

Fig. 8 Telemetry receiver assembly diagram in air medium

We carried out a series of five measurements for different target distances in air medium (Table II).

TABLE II TARGET DISTANCE MEASUREMENTS IN AIR MEDIUM

Distance (cm)	Δt moy(ms)	D (cm)	Error(%)
20	1,17	19.75	1.2
30	1.80	30.60	2.0
40	2.70	45.90	14.8
50	3.22	54.74	9.48

The proposed system allows relatively precise measurements over distances of less than 30 cm target. When the distance increases, the received signal loses amplitude, and therefore requires a greater amplification. The signal is more noisy and results of 5 consecutive measurements are therefore very variable. In addition, the transmission area and the larger signal transducer can interfere with the room environment.

C. Modulating Signal for Guiding a Submarine Robot

Ultrasound signal propagates very fast under water. A wall 1m far from the robot will correspond to a delay of 1,3 ms. The pulse width T_H of the *ping* signal must then be as narrow as possible to avoid overlapping and we suggest to use 0,1ms value. The corresponding values for the components are then:

$$C_1 = 0.01\,\mu F - R_1 = 3.9\ k\Omega - R_2 = 1.0\ M\Omega - R_3 = 10\ k\Omega$$

The T_L value is then about 7 ms.

We carried out underwater measurements using a 3 meters long canal (see Fig.9). The data acquisition is made by a JEULIN © Visio Plus card and the "Atelier scientifique" software. We measured target distances between 50cm and 165 cm. The result sets of measures are presented in Table III. The errors are evaluated taking into account the time lecture error (0.05 ms)

TABLE III TARGET DISTANCE MEASUREMENTS IN WATER MEDIUM

Distance (cm)	Δt moy(ms)	D (cm)	Error(%)
50	0.37	55.5	11.0
100	0.80	120	20.0
150	1.10	165	10.0

Fig. 9 Hydraulic canal used

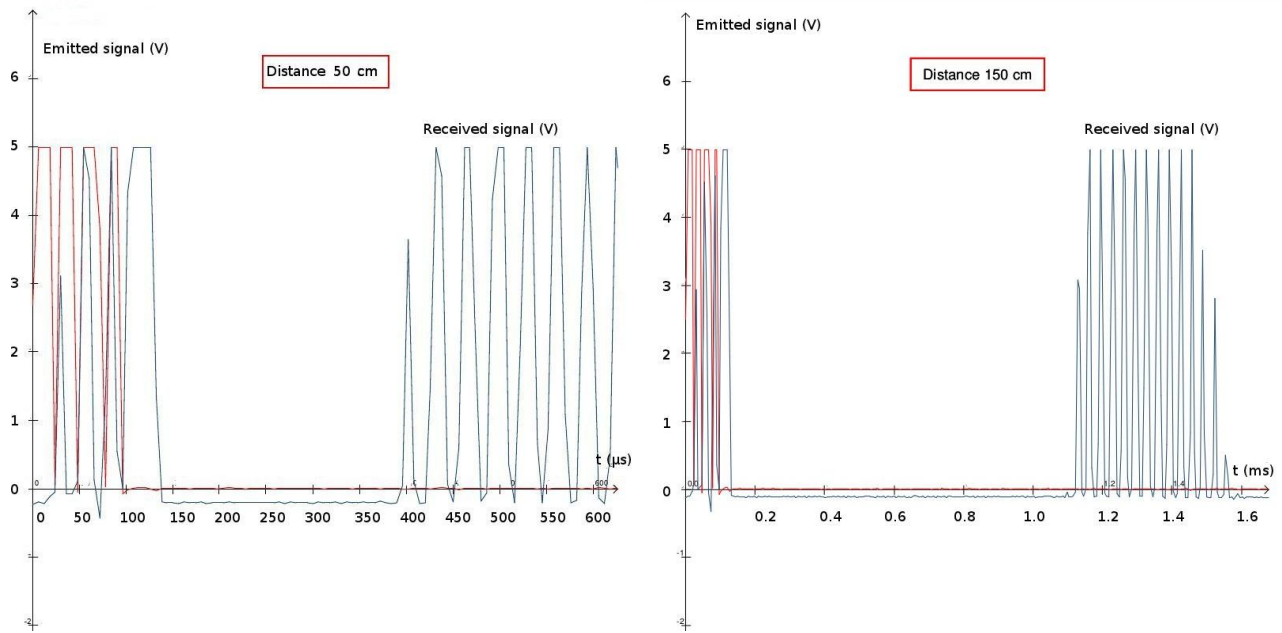Two examples of signals obtained are shown in Figure 10.

Fig. 10 Emitted and received signals with 50 cm and 150 cm distance target.

D. Modulating Coded Signal for Fish Species Study

In the case of fish species study, the emitting signal is coded on several pulses and the pulse period is different from each species [13]. Here we show that our system can be used for this application. An example of a 4 pulses signal code with 1ms width is presented here.

A modulated square pulsed signal of 2 ms period is first created with the 40 kHz oscillator and a first NE555 with following components values:

$$C_1 = 0{,}1 \ \mu F \ \text{-} \ R_1 = R_2 = 3{,}9 \ k\Omega \ \text{-} \ R_3 = 10 \ k\Omega$$

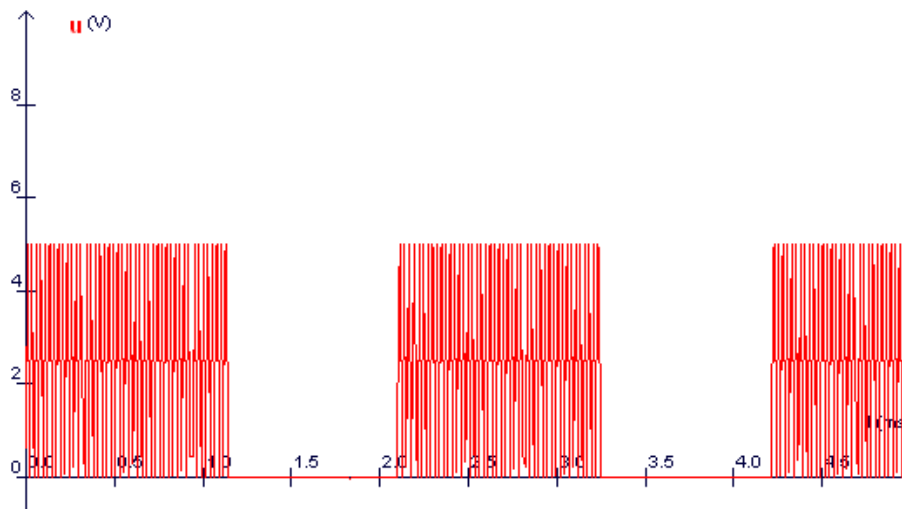This signal is presented in Figure 11.

Fig. 11 Square pulsed modulated signal.

Four period of this signal are then selected in a pulse by using a second NE555 which output is connected to the first circuit power. The desired pulse width is 8 ms and the delay time as longer as possible. The component choosen values are:

$$C_1 = 1 \ \mu F \ \text{-} \ R_1 = 1{,}5 \ k\Omega \ \text{-} \ R_2 = 1 \ M\Omega \ \text{-} \ R_3 = 10 \ k\Omega$$

The delay time is then 0,7 s. The final output signal is showed in Figure 12.
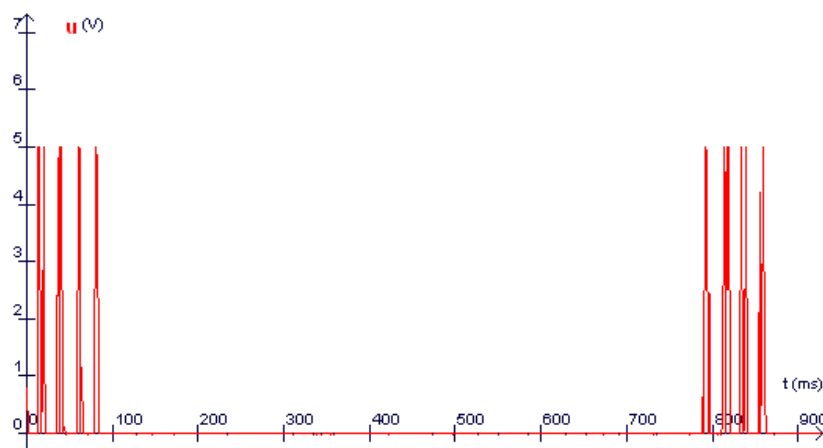
Fig. 12 Final coded signal.

V. CONCLUSION

We presented emitting signal for ultrasound air and underwater applications. The circuits based on NE555 multivibrator are very simple to use: the pulse width and the delay time can easily be changed according to the propagation media and the distance to be detected.

For last application, miniaturization of the circuit is necessary because the system must be ingested by fish. The frequency used is typical 63 kHz because of the sensor size, and the battery must be included. We shown that our circuit could be suitable for this application type.

The sealing of the sensor have to be tested at greater depths before using on the underwater robot. The accuracy of the first measurements presented here is sufficient to detect wall or obstacle under water and to avoid it. The emitting and receiving printed circuits have tobe included within the muffs of the sensors to get complete autonomy .

REFERENCES

[1] http://www.med.univ-tours.fr/recherche, Le Monde des Ultrasons.

[2] Xavier Lurton, Acoustique sous-marine - présentation et applications (Editions IFREMER, 1998).

[3] Sylvie Breton, Stéphane Rochard, Christian Jaouen, Magloire Abouna, Conception et réalisation d'un circuit d'émission ultrasonore autonome et souple d'utilisation *CNR'IUT 2006,* June 1-2, 2006, Brest, France, session EP2, www.cnriut.fr (6 pages).

[4] http://www.sinaptec.fr/ultrasons, Principes généraux.

[5] M. R. Heulpel, J. M. Semmens and A. J. Hodbay «Automated acoustic tracking of aquatic animals. », Marine and freshwater Research, 57, 1-13.

[6] Luc Paradis, *Développement de Méthodes et d'un dispositif de Traitement du Signal adaptés au Contrôle Non Destructif par Ultrasons*, Ph.D. dissertation Institut National Polytechnique de Grenoble, 1983.

[7] A. Ravasoo, J. Janno, Acta Mechanica, «Nondestructive characterization of materials with variable properties », 151,217-233, 2001.

[8] Culjat, Martin O.; Goldenberg, David; Tewari, Priyamvada; Singh, Rahul S.: A Review of Tissue Substitutes for Ultrasound Imaging; Ultrasound in Medicine & Biology 36(6), 2010.

[9] http://www.massa.com/fundamentals.htm

[10] http://easy-electronics4u.blogspot.fr/2012/02/simple-rectangular-oscillator-using.html

[11] Zarah Apert, *Utilisation de l'acoustique ultrasonore pour la caractérisation de matériaux – mise en étanchéité des sondes pour la focalisation du faisceau*, Master PCI training dissertation , Université de Bretagne Occidentale, May-June 2007

[12] NE555 Data sheet and application note

[13] VR2W and VR100 Acoustic Transmitters Data sheet , VEMCO AMIRIX System, Canada

Sylvie Breton Lojou was born in Toulouse, France, in 1960. She received the M.Sc. and Ph.D degrees in electrical engineering from the University of Rennes, Rennes, France, in 1984 and 1989, respectively.

Since September 1989, she has been an Associate Professor with the Institut Universitaire de Technologie of Brest, University of Brest, Brest, France. She was a Research Associates with the LEST Telecom Bretagne from 1989 to 2004, working on material dielectric microwave characterization. Since 2005, she has been a member of the LBMS Lab (EA 4325) working on NDT.

Mohamed El Hachemi Benbouzid was born in Batna, Algeria, in 1968. He received the B.Sc. degree in electrical engineering from the University of Batna, Batna, Algeria, in 1990, the M.Sc. and Ph.D. degrees in electrical and computer engineering from the National Polytechnic Institute of Grenoble, Grenoble, France, in 1991 and 1994, respectively, and the Habilitation à Diriger des Recherches degree from the University of Picardie "Jules Verne," Amiens, France, in 2000.

After receiving the Ph.D. degree, he joined the Professional Institute of Amiens, University of Picardie "Jules Verne," where he was an Associate Professor of electrical and computer engineering. Since September 2004, he has been with the Institut Universitaire de Technologie of Brest, University of Brest, Brest, France, where he is a Professor of electrical engineering. His main research interests and experience include analysis, design, and control of electric machines, variable-speed drives for traction, propulsion, and renewable energy applications, and fault diagnosis of electric machines.

Prof. Benbouzid is a Senior Member of the IEEE Power Engineering, Industrial Electronics, Industry Applications, Power Electronics, and Vehicular Technology Societies. He is an Associate Editor of the IEEE TRANSACTIONS ON ENERGY CONVERSION, the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, and the IEEE/ASME TRANSACTIONS ON MECHATRONICS.