The Temperature Influence on the Piezoelectric Transducer Noise, Measurements and Modeling.

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***Abstract*— In many case, the SNR limit the performance of a transducer. The understanding of the nature and the behavior of the noise allow to increase this SNR. First, we present the noise and impedance real part measurement results in air and in water. We show the link between them. The second part is a temperature study which confirms this influence. We show the little evolution of the total output noise in a conditioning chain. Finally, we use a derivate of Redwood electro-acoustical model to estimate the noise. The measurement results agreed with this one.**

Transducer, Noise, Temperature, Model PSPICE

I. INTRODUCTION

This work, developed at the Electronic Laboratory of Instrumentation of Nancy (LIEN-France), concerns the characterization of the electrical impedance and the generated noise of piezoelectric transducers. Special attention is given to the medium of propagation and the temperature on the noise level. Theoretical explanations are proposed to justify the relative thermal stability of the noise level.

This paper is composed of four parts. The first one considers measurements of the complex impedance and the spectral noise density of the piezoelectric transducers and are carried out in water and in air. All measurements are made using the impedance analyzer HP4195A and the spectrum analyzer Advantest R3131A. Because the noise level of the sensor is very low, we insert an amplifier between the analyzer and the sensor. This amplifier increases the level of signal above the noise floor and adapts the impedances. The transducers are made of PZT and their resonance frequencies are situated around 2 MHz. The measurements are realized at a temperature fixed to 298 K. We measure the correlations between the noise spectrum and the impedance.

In the second part, we study the influence of the temperature T on the impedance and the noise spectrum for square transducers in air. The temperature range is 298 to 343 K. In this range, the magnitude of the impedance peak decreases by 0.3 % per K and its relative frequency shifts by 186 ppm per K. The temperature seems to have a little influence on the noise level: the peak magnitude is nearly constant, with a sensibility coefficient equal to 0.08 % per K. Then we provide suggestions of theoretical interpretations of the observed results.

In the last part, we propose a electroacoustic model (type Redwood) which includes an estimate of the transducer noise. Currently, this model implemented under PSPICE allows to evaluate the signal-to-noise ratio of ultrasonic emission reception system.

II. IMPEDANCE AND NOISE MEASUREMENT METHODS AND RESULTS.

A. Theoretical aspects

We want to compare measurements of the impedance with measurements of the power spectral density (PSD) of noise. The principal factors of influence we must take into account in this study are:

- The propagation medium (air and water).
- The temperature of the transducer (in air; the range of temperature is 25°C to 70°C).

We are interested in the noise generated by a transducer in reception, and with its modeling. The noise of the transducer [1] consists of three sources:

- First is due to the thermal noise of the propagation medium [2]. It results in a force generator producing a white noise connected to the mechanical impedance of the medium.
- The two others are linked to the noise associated with the mechanical and electric losses in the piezoelectric material.

An approach would be to consider all the sources of noise independently from the others. Unfortunately, it is difficult to do so in simulations.

Studies showed that the noise is equivalent to the thermal noise produced by Re(Z), the real part of the electric impedance [3] :

$$e_N = 4.k_B.T.Re(Z) \qquad (V/Hz^{0.5})$$

We can thus model all the noises in the transducer by adding in series each tension source of noise.

B. *Experimental Condition*

Square plates (20 mm X 20 mm) of P1-88 are used. Measurements are taken in air and water at fixed and variable temperature. The impedance measurement is carried out using a network analyzer HP4195A. The band of analysis covers the range from 2.1 to 2.4 MHz with a resolution of 1 Khz and an average on 10 points.

Because the noise level of the sensor is very low, we use an amplifier between the analyzer and the sensor. The experimental measuring noise network noise is represented in figure 1.

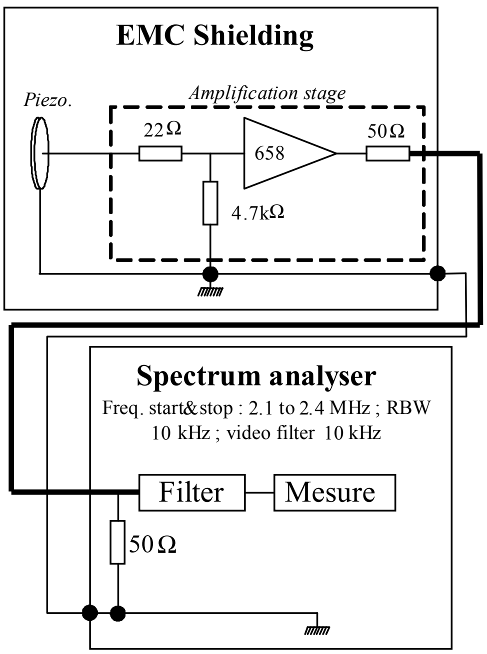

Figure 1. Spectrum Measurement.

The diagram of the amplifier is given in figure 2.

This amplifier increases the signal level above the noise floor and adapts the impedances. It is realized by a two amplifying stages (LMH6624) and an adapting buffer (50Ω).

In the measuring band which goes from 2.1MHz to 2.4MHz, the amplifier has a constant gain of +56,3dB±0,05dB. We measured the noise level at the output of our measuring equipment according to the resistance of source. Table 1 has the results for various values of resistance.

TABLE I. THE AMPLIFIER OUTPUT NOISE LEVEL.

Resistances Value (Ω)	**Noise level to the amplifier ouput ($nV/Hz^{0.5}$)**
0	420
50	520
380	960
∞	2820

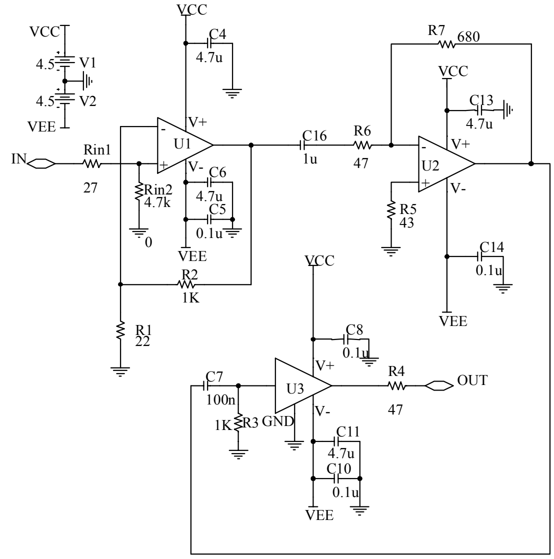

Figure 2. Amplifier.

C. *Measurement Results*

1) *Impedance.*

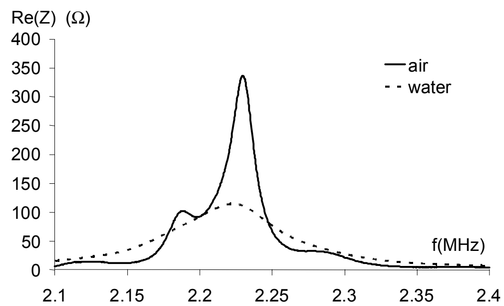

Figure 3. Impedance in different medium

The nature of the medium has an influence on the real part of the impedance of the sensor as we can see on figure 3. We can notice on the curve spurious resonance around 2.19 MHz.

2) *Noise.*

The noise measurement is taken for various mediums (figure 4).

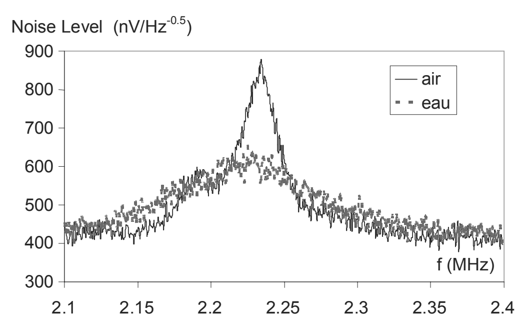

Figure 4. Noise level measurement for different mediums.

III. IMPEDANCE AND NOISE TEMPERATURE INFLUENCE AND INTERPRETATION.

1) Impedance.

When the air temperature increases, we note a linear deviation of the maximum value of the impedance and parallel frequency F_P (figure 5).

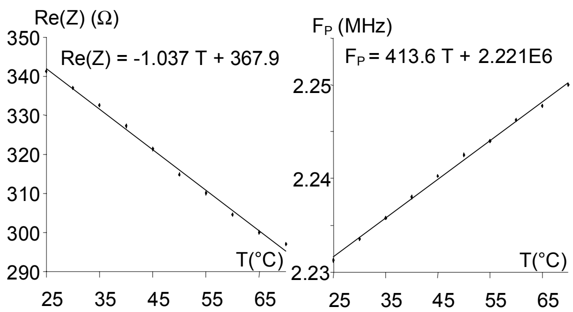

Figure 5. Impedance shift measurement.

The relative variations are:

- -0.4 %/°C for the impedance peak
- +185 PPM/°C for the frequential shift.

2) Noise.

When the temperature of the air increases, we note a linear deviation of the maximum of noise and frequency of this peak as figure 6 shows it. The tendency curve of this frequency has, with a margin of 3%, the same directing coefficient as that of the parallel frequency, and with 45 PPM.

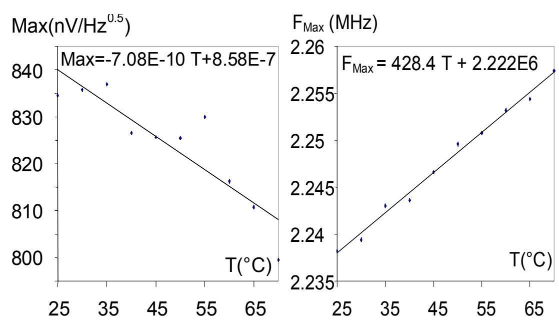

Figure 6. Noise shift measurement.

The results show a relative variation of the peak of impedance of approximately -8.4 PPM/°C. We also find out that there is a total frequential shift of approximately +191 PPM/°C.

3) Interpretation.

The transducer temperature seems to have little influence on the noise level. This stability can be well explained if we consider that the noise is generated by the impedance resistive part. Indeed, the decrease of the resistive part compensates the increase of the thermal noise when the temperature increases.

On one hand, the decreasing impedance is explained by the thermal sensibility of certain characteristics of the piezoelectric material such as the dielectric constant. On the other hand, we show that whatever is the origin of the noise delivered by the transducer (intrinsic or noise introduced by the medium), a Johnson noise explains the quasi-stability of the measurements.

If we consider that the noise is generated by the resistive part R of impedance, the noise PSD is proportional to R_T. This PSD remains constant because the relative decrease of the resistive part (-13.5 %) compensates the relative increase of temperature (+15 %).

IV. NOISE ESTIMATION USING MODIFIED REDWOOD MODEL.

Our work is based on the model of Redwood [4] describe in figure 1. It is improved by including the mechanical [5] and electrical [6] losses.

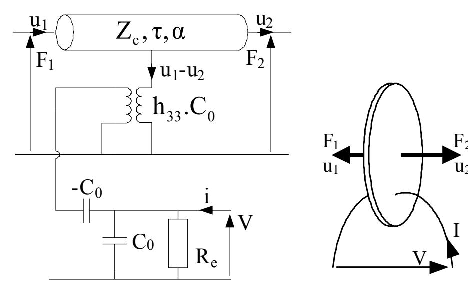

Figure 7. Improved Redwood Model.

Our simulations are carried out on square plates (20 mm X 20 mm) of P1-88. The principal characteristics of piezoelectric material are summarized in table 2.

TABLE II. P1-88 20X20MM TRANSDUCER CHARACTERISTICS.

Parameters	Symbol	Units	P1-88
Thickness of the piezoelectric material	ep	mm	1
Area (0.02x0.02)	S	m^2	0,0004
Density	ρ	10^3 $kg.m^{-3}$	7,7
Relative permittivity	ε_r	-	837
Piezoelectric coefficient	h_{33}	10^8 $V.m^{-1}$	22,6
Acoustic impedance of piezoelectric material	Z_{Piezo}	M Rayls	34,9
Acoustic impedance of the backing (air)	$Z_{Backing}$	Rayls	415
Tangent of the dielectric loss angle	tg δ_e	%	2
Tangent of the mechanical loss angle	tg δ_m	%	1,25

AC simulation of the model makes it possible to plot the curves of the electric impedance and the spectral density of noise generated by the transducer. These ones are simulated around the frequency of antiresonance which is 2,265 MHz. We note in figure 8 the great influence of the nature of the medium on the real part of the impedance. The value of Re(Z)max equals 106 Ω in water and 281 Ω in air.

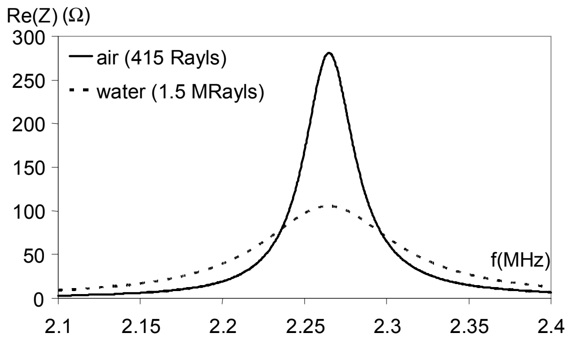

Figure 8. Real part of the transducer impedance.

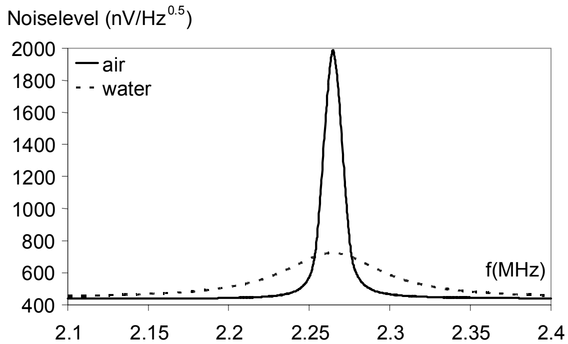

Figure 9. Noise level at the transducer-amplifier output.

The PSD of noise estimated at the end of our instrumentation chain is represented in figure 9. This one is correlated with the real part of the impedance. The noise is located around the frequency of resonance. We can evaluate the influence of the medium on the noise at the output of the chains: 1985 nV/Hz $^{0.5}$ in air against 724 nV/Hz $^{0.5}$ in water.

V. CONCLUSIONS

Some simulation tests added to experimental measurement show the relationship with the impedance and the piezoelectric transducer's power spectral density of noise. We also show in this study the temperature influence. The impedance presents a negative thermal sensitivity. The noise power spectral density is almost steady when the temperature changes. These results can be explained by considering that the transducer noise model is a thermal noise kind.

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