THE INVESTIGATION OF FILTERS FOR REAL-TIME DATA ACQUISITION

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Abstract

Estimation of sound pressure level by using less expensive PVDF and $BaTiO_3$ multilayer ceramic ultrasonic transducers has been investigated. Calibration of proposed transducers was done with the help of commercial hydrophone HNP-1000 from Onda Corp., Sunnyvale. This work compares these less expensive transducers against hydrophone in sound pressure sensitivity over 1 MHz to 15 MHz frequency range. Experimental results are presented. The proposed inexpensive sensor design is using high voltage multilayer ceramic capacitor. It has indicated good sensitivity (0.5 μV/Pa to 3 μV/Pa) over frequencies 1 MHz to 8 MHz.

1. Introduction

The performance estimation of the sonoporation, therapeutic ultrasound, high intensity focused ultrasound (HIFU) [1], diagnostics and imaging equipment requires the acoustic pressure estimation [2]. Usually investigation is carried out using expensive hydrophone. Furthermore, hydrophone usually is made using Polyvinylidene Fluoride (PVDF) film and it is very sensitive to the mechanical damage [3]. When high intensity ultrasound is used, cavitation might rip out the PVDF metallization. It is desired to have the inexpensive sound pressure registration equipment with moderate sensitivity and accuracy. Experimental investigation of possible candidates is presented below.

2. Sensor requirements

Usual measurement procedure (Figure 1) involves the hydrophone as the local pressure sensor: hydrophone size is desired to be small. Results of Apfel and Holland presented in [4] indicate that at 1 MHz frequency the inertial cavitation threshold is 0.25 MPa of peak negative pressure; 0.6 MPa at 5 MHz and 0.85 MPa at 10 MHz. When hydrophone is used to determine how close the radiation is to the aforementioned thresholds, high sensitivity is not necessary. Intensities used in HIFU [5] can reach 30 MPa in compression and 10 MPa in negative peak pressure with optimal frequencies 0.7 MHz to 3 MHz [6]. Such pressures can damage the expensive sensor in case of long term use.

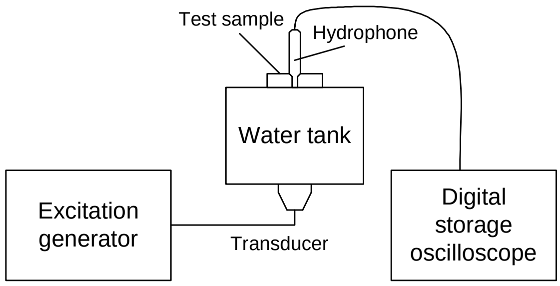

Figure 1. Hydrophone measurement

Such sensor also is used in transducer directivity study [7]. For general purpose studies the bandwidth beyond 5 MHz is sufficient.

3. Proposed sensors design

Two types of transducers were chosen for evaluation. One candidate was the epoxy-coated PVDF. Another was multilayer ceramic capacitor with sufficient $BaTiO_3$ content.

3.1. PVDF-based sensor

The main problem associated with PVDF application in pressure sensing is the rip off of the electrode due to cavitation. One of the possible solutions could be to coat the PVDF electrode with more durable material. We had such candidate available. It had epoxy coating in front of 2.5 mm diameter PVDF film. Coating was also used for focusing: sensor had about 10 mm focal distance. Encapsulated transducer had 4 mm diameter.

On the other hand such design does not allow point pressure measurement: the result is the integrated pressure over the sensor's area.

3.2. BaTiO3-based sensor

The multilayer ceramic capacitor (MLCC) usually has high capacitance thanks to high dielectric permittivity of the $BaTiO_3$ used as dielectric. The $BaTiO_3$ has piezoelectric properties. Therefore it was decided to use MLCC as sensing element. The idea of MLCC with $BaTiO_3$ use as the piezo-sensor is not new: authors [11] report MLCC use as inexpensive force sensor array. Capacitor is very small, cheap and has readily metallization. Thanks to multilayer structure it has to be better matched to coaxial cable impedance. It should be easy to polarise thanks to low Curie temperature (120°C) and high field strength thanks to multilayer structure (Figure 2).

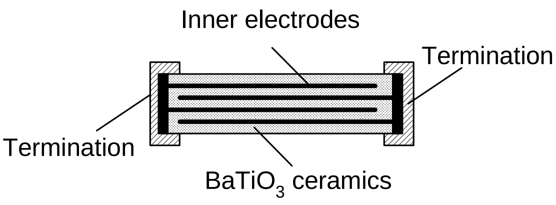

Figure 2. MLCC structure

The 1 nF 1206 size (3.2x1.6 mm and 1.25 mm thickness) 630 V MLCC with X7R class dielectric was chosen for experiments. Experiments were carried out to evaluate the most sensitive arrangement of the MLCC position in sensor (Figure 3).

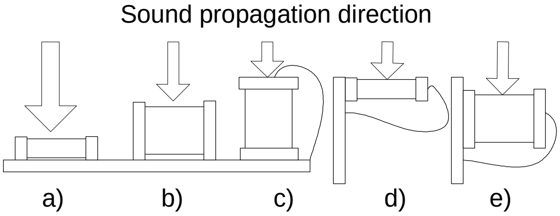

Figure 3. MLCC arrangement for sensitivity investigation

The spherically focused ultrasonic transducer by Karl Deutsch (model TS 12PB2-7P30; frequency range 1 MHz to 6 MHz, diameter 12 mm) was used as ultrasound source. Acoustic beam of this transducer was investigated. Assessment was made using the 1 mm steel wire reflector in pulse-echo operation mode [7]. Investigation of beam profile in longitudinal direction has revealed that peak intensity is at 27 mm (Figure 4). The lateral beam size is about 1.5 mm.

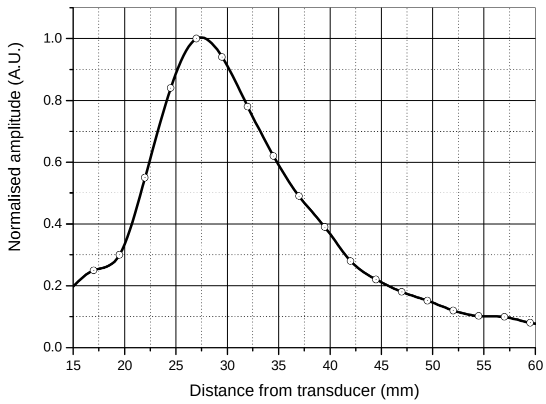

Figure 4. Acoustic source performance along transducer axis (longitudinal)

Sensor was placed at 27 mm distance from acoustic source according the Figure 1. Pulse trains of 2.7MHz frequency (transducer center frequency) 100Vpp square pulses were used for transducer excitation. The sensor output signal was averaged by scope (Hameg HMO3524) and peak negative voltage was registered.

Sensor was investigated in poled and un-poled conditions. Poling was performed using 500V source and 150°C hot air flow. Obtained results are grouped in Table 1.

Table 1. Transducer parameters

Arrangement	*a*	*b*	*c*	*d*	*e*
Ouput signal, unpoled, mVpp	4	1	4	8	2
Ouput signal, poled, mVpp	12	-	18	40	-

From Table 1 analysis it was decided to use arrangement d) for final sensor construction (Figure 5).

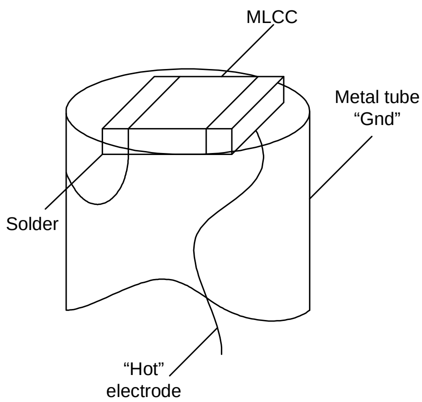

Figure 5. BaTiO3-based sensor construction

MLCC was placed inside the 100 mm long 3 mm diameter tube and coaxial cable attached at the end.

4. Sensitivity investigation

Acoustic effect parameters can be assessed with the help of professional hydrophone. We have used the commercial hydrophone HNP-1000 from Onda Corp., Sunnyvale (Figure 6: sensitivity over frequencies range corrected according to [8]).

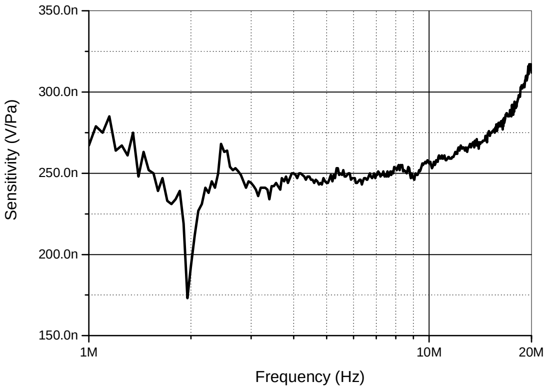

Figure 6. Hydrophone sensitivity

The sensitivity M of hydrophone was corrected using the hydrophone output capacitance $C_h(f)$ given in data sheet and the input capacitance C_{in} of the reception channel (oscilloscope) [8]:

$$M_c(f) = \frac{M(f)C_h(f)}{C_h(f)+C_{in}} , \quad (1)$$

Manufacturer declared calibration uncertainty is ± 1 dB for 1 V/µPa [9]. This hydrophone was used as reference for calibration.

Same focused ultrasonic transducer by Karl Deutsch was used as ultrasound source. Acoustic source was placed at 27 mm distance from investigated sensor according the Figure 1. Arbitrary waveform generator Rigol DG1022 was placed into CW sine wave burst mode. Output voltage was 10 Vpp. The hydrophone signal was averaged by scope and peak negative voltage was registered. The obtained voltage was converted into pressure using (1). Refer Figure 7 for registered acoustic peak negative pressure AC response.

Actual transducer peak is at about 2.7 MHz. The obtained pressure was stored as reference.

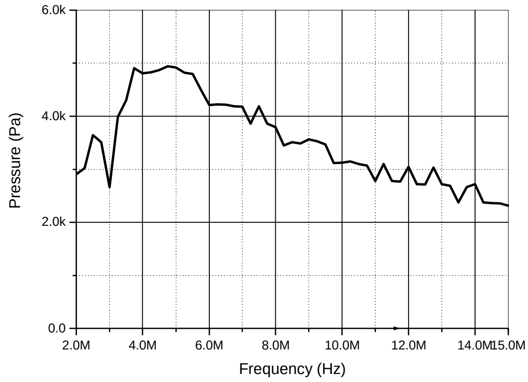

Figure 7. Peak negative pressure AC response for acoustic source

Then the pin transducer was placed at same location and the peak negative voltage on transducer registered. The voltage registered by pin transducer V_P was converted into sensitivity using the pressure P_h registered by hydrophone:

$$M_P(f) = \frac{V_P(f)}{P_h(f)} = \frac{V_P(f)\cdot M_C(f)}{V_h(f)} , \quad (2)$$

Results of obtained pin transducer sensitivity are presented in Figure 8.

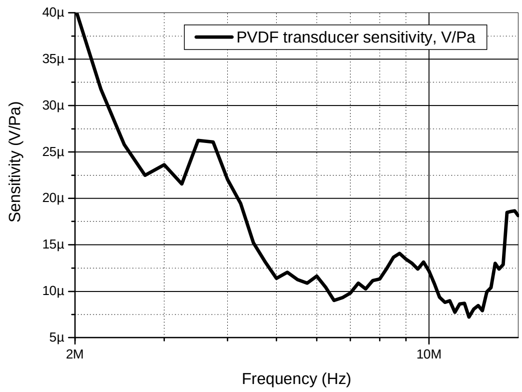

Figure 8. PVDF transducer sensitivity

It can be concluded that PVDF-based transducer has better sensitivity: almost 100 times higher, but the response in not as flat as the hydrophone (refer Figure 9 for comparison in dB).

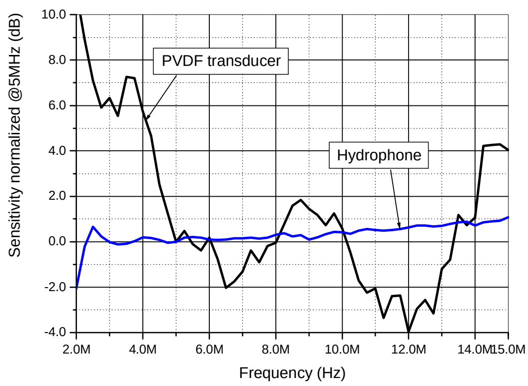

Figure 9. Sensitivity AC response comparison in dB @ 5 MHz

Another transducer, made from multilayered $BaTiO_3$ was investigated the same way (Figure 10).

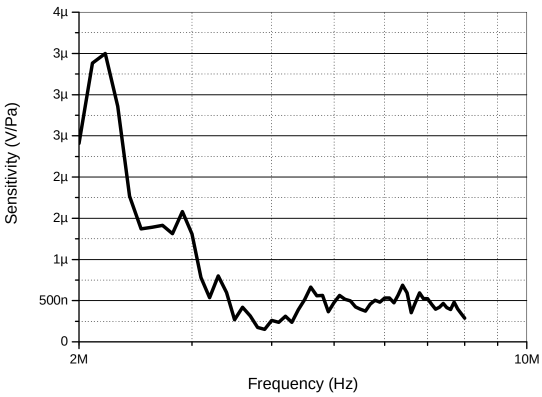

Figure 10. $BaTiO_3$ sensor sensitivity

This transducer has lower sensitivity than PVDF sensor and variation in frequency response is much higher (refer Figure 11 for sensitivity comparison normalized @ 5 MHz).

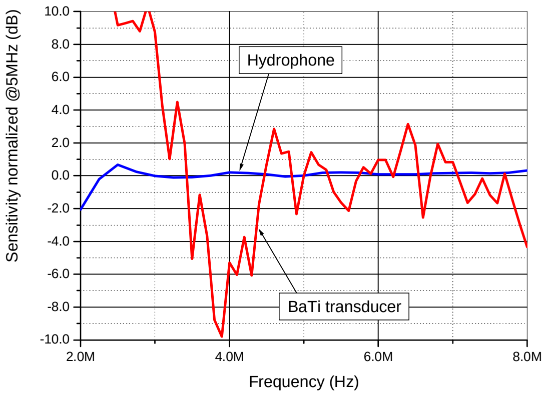

Figure 11. BaTiO3 sensor sensitivity comparison in dB @ 5 MHz

Unfortunately, scope sensitivity was too low to register the signals reliably. Therefore signals at frequency range above 3 MHz were not stable to be registered. In future research the automated received voltage estimation has to be established. It can be done using sine wave correlation technique and automated acquisition system [10]. It can be seen that despite low sensitivity $BaTiO_3$ sensor also has acceptable sensitivity variation at higher frequencies within 3 dB. Sensitivity variation can be reduced using the damping of the backing layer.

5. Conclusions

Application of much cheaper pressure sensors AC response was studied. It has been concluded that measurements still can be carried out since sensors calibration is possible. Using commercial, wideband hydrophone we were able to obtain the sensitivities for our sensors. After calibration, new sensors can be used instead of expensive hydrophone. Later, when rough estimation has been carried out using the cheaper sensors, final performance verification can be done using the expensive hydrophone. Such approach allows guarding the expensive hydrophone from possible damage during the extensive, long-lasting examinations. Future research should investigate the bandwidth improvement, AC response variation reduction techniques and better performance estimation equipment. Sensor linearity has to be investigated and compared against the commercial hydrophone.

6. Acknowledgment

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