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# Measurement of impedance and sensitivity of electroacoustic transducers

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**Abstract**. In the paper a methodology is presented for electroacoustic transducer impedance and transmitting sensitivity measurement. Loaded transducer electrical impedance is measured in water test tank. The methodology for measurement of transmitting sensitivity is based on the pulse method. Experimental results are presented for measured impedance and sensitivity of piezoceramic disc transducer in water filled test tank.

## 1. Introduction

Electroacoustic transducer is a device for transforming electrical energy into mechanical acoustic energy and vice versa. It is represented as an electro-mechanical circuit with electrical and mechanical inputs [1]. The electrical impedance of the transducer is its impedance $Z_{el}$ measured at electrical input. Even though the impedance is measured electrically it depends on mechanical and acoustical (radiation) parameters of the transducer – figure 1.

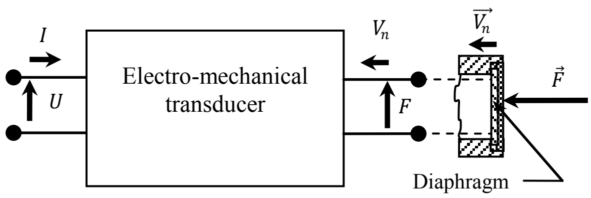


**Figure 1.** Electroacoustic transducer represented as electro-mechanical circuit.

Electrical impedance is measured at the electrical input of the transducer [1]:

$$Z_{el} = \frac{U}{I} \tag{1}$$

Electrical impedance is related to acoustic impedance [1]:

$$Z_{ac} = \frac{F}{V_n}, \tag{2}$$

where $V_n$ – normal speed of diaphragm; F – force (pressure) upon diaphragm.

It is important to measure transmitting sensitivity of a transducer as a function of frequency. For an unknown transducer measurement first of electrical impedance may show resonant frequencies where there is maximal acoustical energy transmission (transformation of electrical input energy into motional acoustical energy) or series resonances where the normal speed of the diaphragm has maximum. This corresponds to conductance maximum in the electrical input of the transducer.
Important parameters of an electroacoustic transducer are his receiving and transmitting sensitivities. The receiving sensitivity is [2]:

$$S_H = \frac{e}{p}, \tag{3}$$

where ***e*** is the effective electrical voltage at its output, ***V***; ***p*** is effective acoustic pressure in the place of the hydrophone, ***Pa***.
The required dimension of the receiving sensitivity is logarithmic - ***dB re 1μPa/V***.
Transmitting sensitivity is [2]:

$$S_V = \frac{p}{E}, \tag{4}$$

Where ***E*** is the electrical voltage at the input of the transducer, ***V***; ***p*** is the acoustic pressure at distance ***1m*** from the transducer, ***Pa***.
The required dimension of the transmitting sensitivity is ***dB re V /μPa at distance 1 m*** from the transducer. The experimental investigation of the transducer frequency impedance response as well as response for the transmitting sensitivity allows its performance to be estimated as a function of frequency. Mechanical quality factor can be estimated from the transmitting sensitivity frequency response [2]:

$$Q_m = \frac{f_0}{\Delta f}, \tag{5}$$

where $f_0$ is the series resonance frequency, $\Delta f$ is the bandwidth between frequencies where there is two times fall of the transmitted acoustical intensity relative to the maximum at resonance.
Subject to experimental investigation in our case is a disk piezoceramic electroacoustic transducer with diameter of the diaphragm - 70 mm – figure2. The investigation is carried out in a filled with water test tank with the developed in [3] pulse measurement methodology.

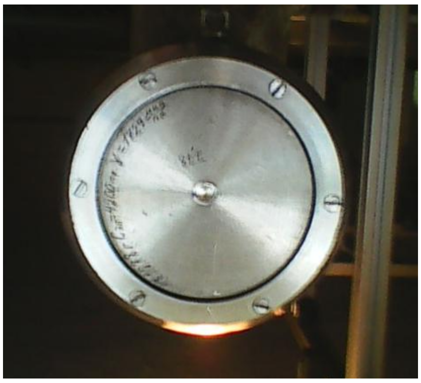

**Figure 2.** Disk electroacoustic transducer subject to investigation.

## 2. Measurement methodology for transmitting sensitivity of an electroacoustic transducer

Methodology for test tank electroacoustic pulse measurements of directional pattern of a disk transducer was presented in [3]. Functional diagram of the transducer transmitting sensitivity measurement is presented on figure 3. Green lines show electrical input to industrial PXI system from power amplifier and preamplifier while the red line shows transducer stimulus signal to the power amplifier.

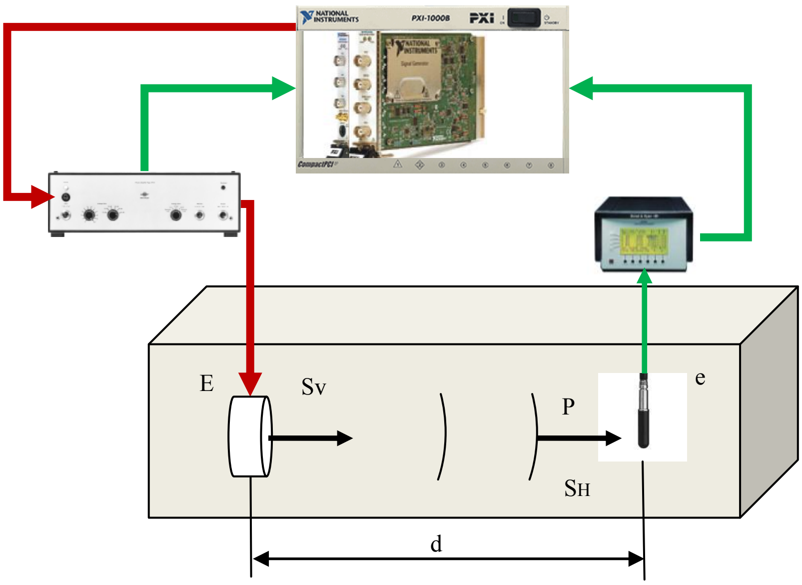


**Figure 3.** Test tank experimental setup for measurement of transmitting sensitivity.

The unknown transmitting sensitivity of an electroacoustic transducer is measured with relative calibration by the comparison method [1]. The pressure at distance ***d*** from the transducer is measured with previously calibrated hydrophone [4]. If an effective voltage ***E*** is applied at the transducer with transmitting sensitivity $S_V$ , the sound pressure at distance ***d*** will be:

$$p = \frac{E.S_V}{d} \tag{6}$$

In expression (6) it is assumed that a spherical wave is transmitted from the transducer and its effective pressure ***p*** is measured at relatively far distance ***d***. It is known that for radiated sphere wave the pressure at distance ***d*** will be ***d*** times smaller (inverse proportion) than the pressure at distance 1 m from the transducer which is $S_V$ . From (3) and (6) it follows that the unknown transmitting sensitivity is:

$$S_V = \frac{d.p}{E} = \frac{d.e}{E.S_H} \tag{7}$$

Usually we measure effective voltage at the output of the calibrated hydrophone with sensitivity $S_H$ through calibrated charge preamplifier BK2692 connected to the hydrophone.

In logarithmic units expression (7) is:

(8) $$20\log_{10} S_V = -20\log_{10} E - 20\log_{10} S_H + 20\log_{10} d + 20\log_{10} e$$

A calibrated power amplifier BK2713 and preamplifier BK2692 are used to measure precisely voltages ***E*** at the input of the transducer and voltage ***e*** at the output of the preamplifier. Distance ***d*** is controlled trough LabVIEW motion interface and precisely measured.

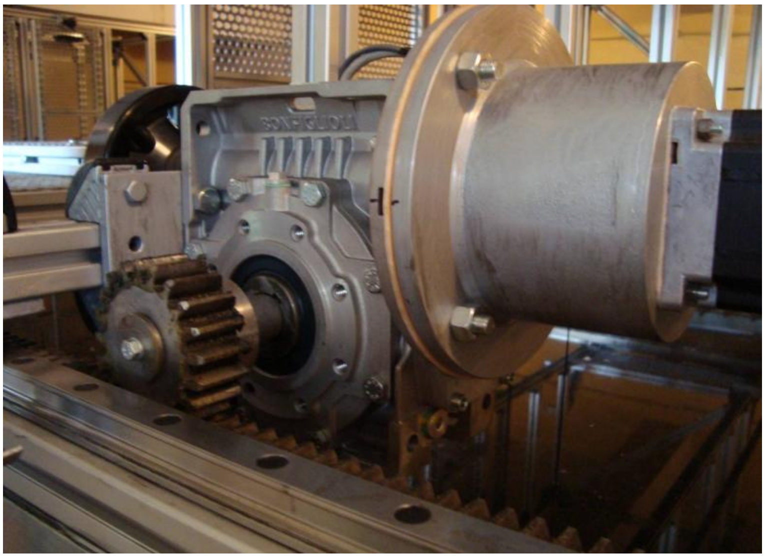

**Figure 4.**Mechanical part – stepped motor with gear of the test tank frame linear motion interface.

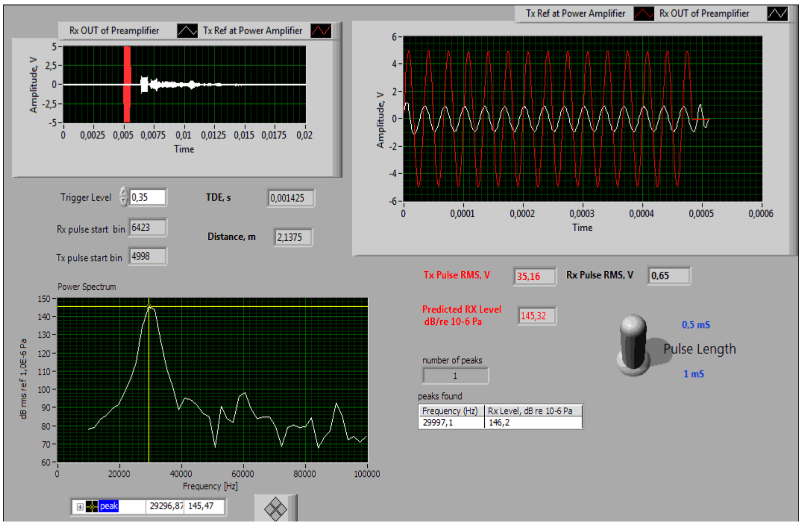


**Figure 5.** Front panel of virtual instrument for estimation of test tank pulse signals SPL.

In order to estimate quality of the assumption that an impulsive sound field may have sphere wave front according to (6) a measurement was made of the SPL of transmitting hydrophone BK8104 with varying from 1,32 m to 3,72 m distance to the receiver for frequency 20 KHz. Transmitted pulses have pulse width 0,5 ms. Depth of the transmitting hydrophone is 1,7 m, while the depth of the receiving hydrophone BK8100 is 1 m. The mean error between the theoretical SPL and measured SPL is -0,07 dB, while the RMSE error is 0,23 dB.

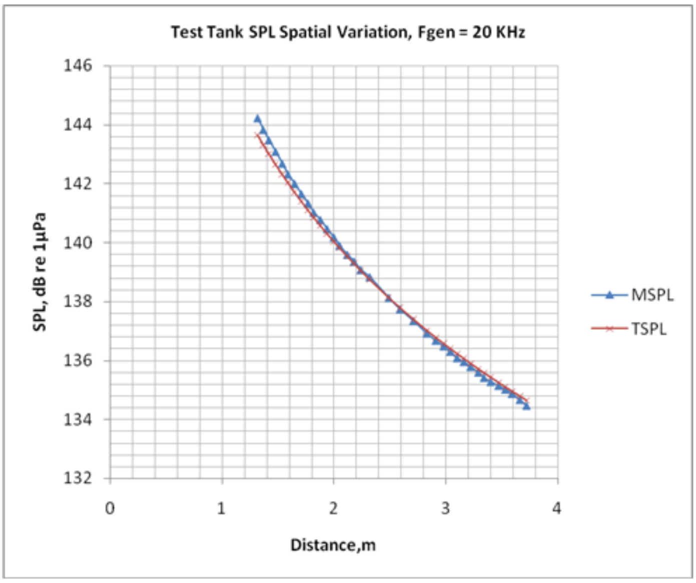


**Figure 6.** Comparison between measured SPL (MSPL) and theory SPL (TSPL) for spherical wave front at different distances from the transducer BK8104.

Comparison of measured transmitting sensitivity of BK8100 hydrophone compared with BK nomograme is given on figure 7.

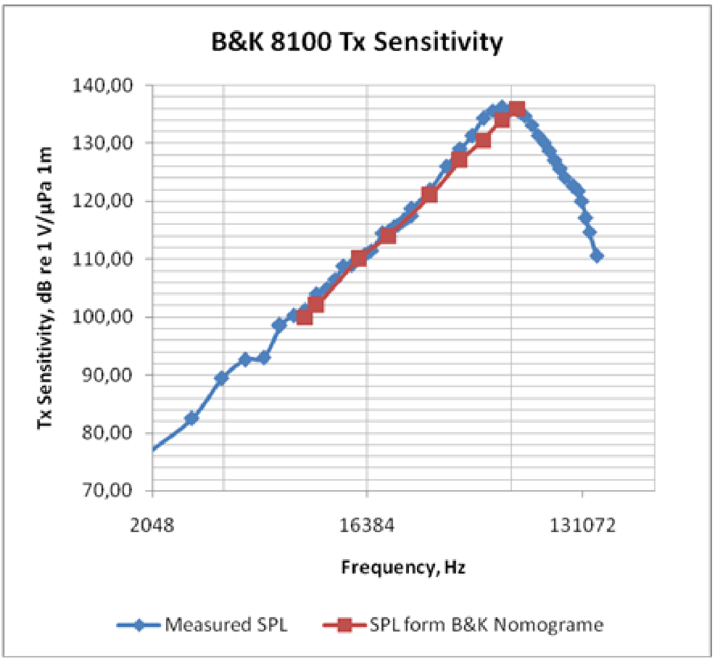


**Figure 7.** Measured transmitting sensitivity of BK 8100 hydrophone.

### 3. Measurement methodology for electrical impedance of an electroacoustic transducer

Measurement of electrical impedance is carried out using known methodology for measuring complex impedance of ceramic transducer. It is based on investigation in [5,6].

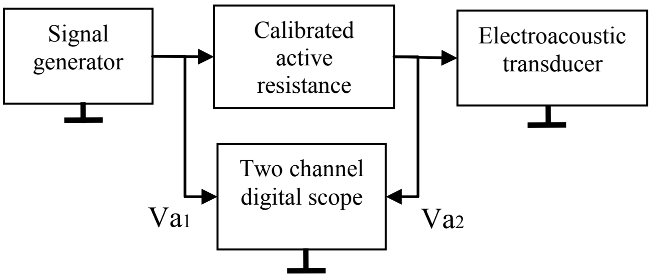


**Figure 8.** Experimental setup for measuring complex impedance of electroacoustic transducer.

The impedance measuring technique uses two voltage waveforms Va1, Va2 at indicated points on figure 8 to calculate the unknown impedance – Zel [6].

(9)
$$Z_{el} = \frac{V_{A2}}{I} = \frac{V_{A2}}{V_{A1} - V_{A2}} R_{ref}$$

The impedance is complex. The magnitude is given with the expression [6]:

(10)
$$|Z_{el}| = \frac{V_{A2} R_{ref}}{\sqrt{{V_{A1}}^2 - 2V_{A1}V_{A2}cos(\theta) + {V_{A2}}^2}}$$

Where θ is the phase difference between two waveformsVa1, Va2.
Then the impedance phase angle is [6]:

(11)
$$\alpha = \theta - tan^{-1}\frac{-V_{A2}sin(\theta)}{V_{A1} - V_{A2}cos(\theta)}$$

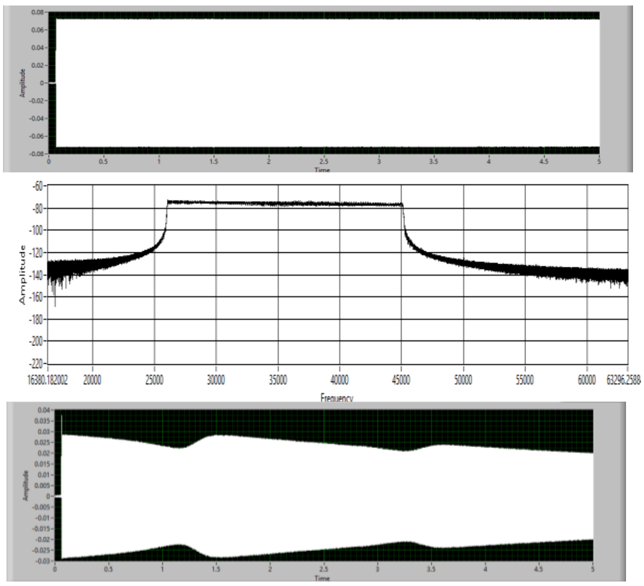

**Figure 9.** Stimulating linear frequency modulated voltage time and frequency domain signal and measured voltage waveform Va2.

Phase sensitive measurements are done with designed LabVIEW virtual instrument. Even though the measurement technique is relatively simple compared to complex impedance bridge meters it is comparatively accurate enough. Figure 10 shows front panel of a virtual instrument for measurements of frequency, $Va_1$, $Va_2$ and phase difference angle θ between two waveforms near resonance of the investigated transducer.

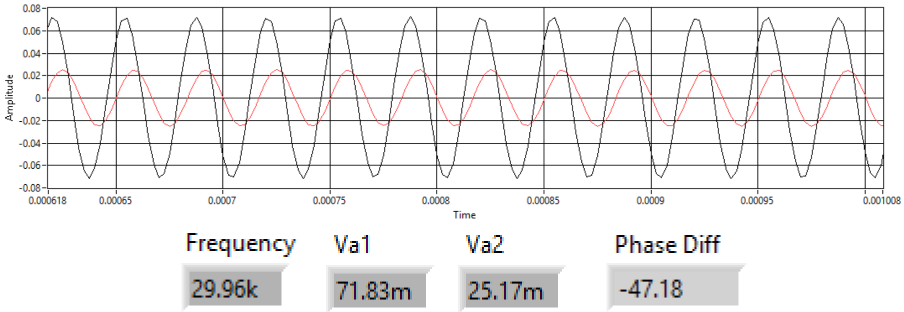


**Figure 10.** Virtual instrument front panel for measurement of frequency, $Va_1$, $Va_2$ and phase difference angle θ between two waveforms near resonance of the investigated transducer.

## 4. Experimental results

### *4.1. Measurement of impedance*

The impedance of the transducer if measured first to estimate frequency response and resonances.

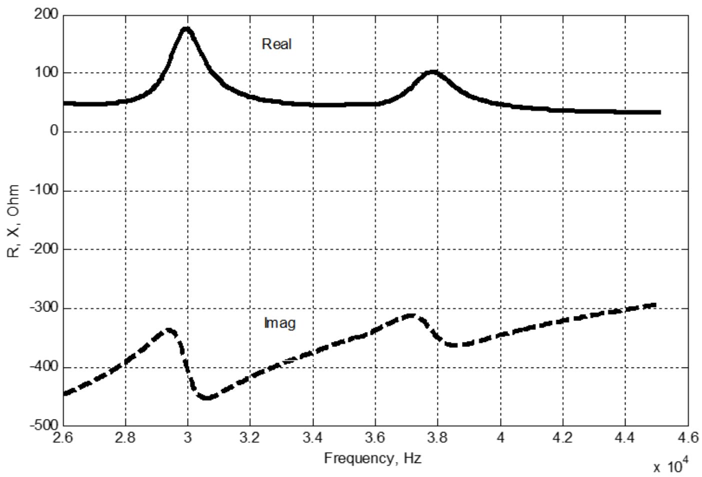


**Figure 11.** Calculated real and imaginary components of the transducer electrical impedance.

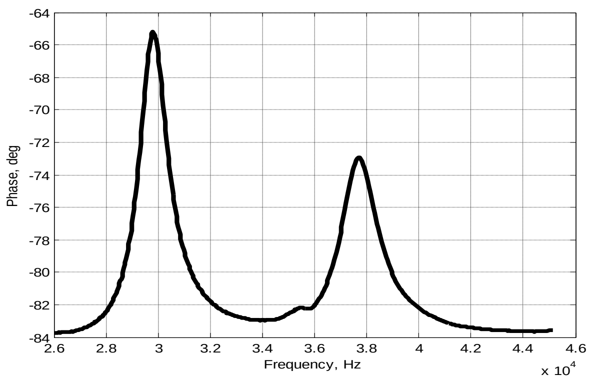


**Figure 12.**Measured electrical impedance phase angle α.

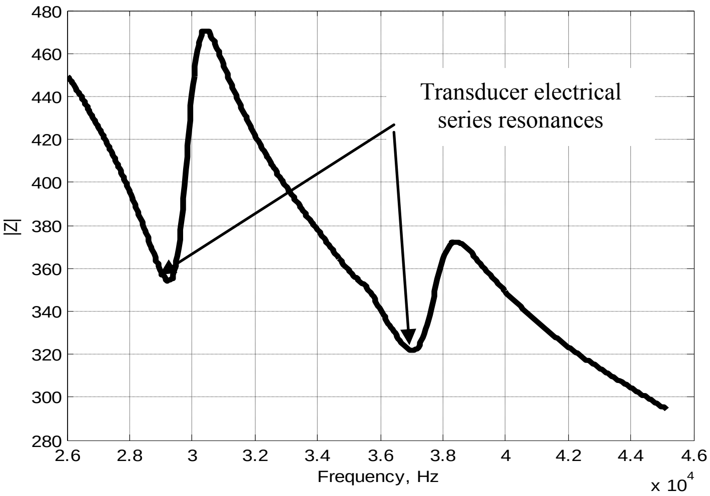


**Figure 13.** Absolute value of the transducer impedance with pointed working points (series resonances) where maximum transmitted sound intensity is expected for maximum normal speed of the transducer diaphragm.

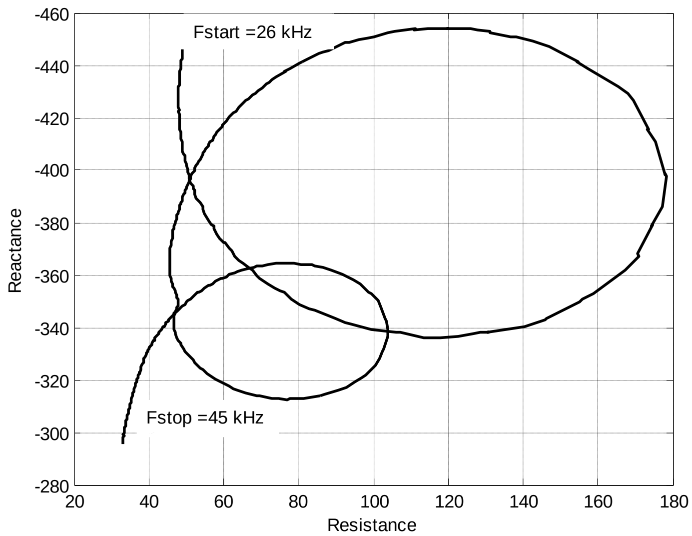


**Figure 14.** Loaded transducer electrical impedance diagram.

Analysis of figures 11-14 allows to estimate the electrical series resonance frequency of the transducer where maximal transmitted sound intensity in the water is expected - $f_0 = 29230\ Hz$.

### *4.2. Measurement of transmitting sensitivity*

The measurement of transducer transmitting sensitivity is done in the area of the first electrical resonance where maximum normal speed of diaphragm is expected. Maxim SPL is measured for frequency - $f_0 = 29505\ Hz$. Pulse method is used with frequency change step 200 Hz from pulse to pulse in the usable frequency range. There is coincidence of the electrical series resonance of the impedance curve with maximum value of the frequency response of the transmitted sound pressure level. It is possible to estimate transducer mechanical quality factor from frequency response of sound pressure level – figures 16, 17 according (5): $Q_m = \frac{f_0}{\Delta f} = \frac{29505}{1691} = 17.4$

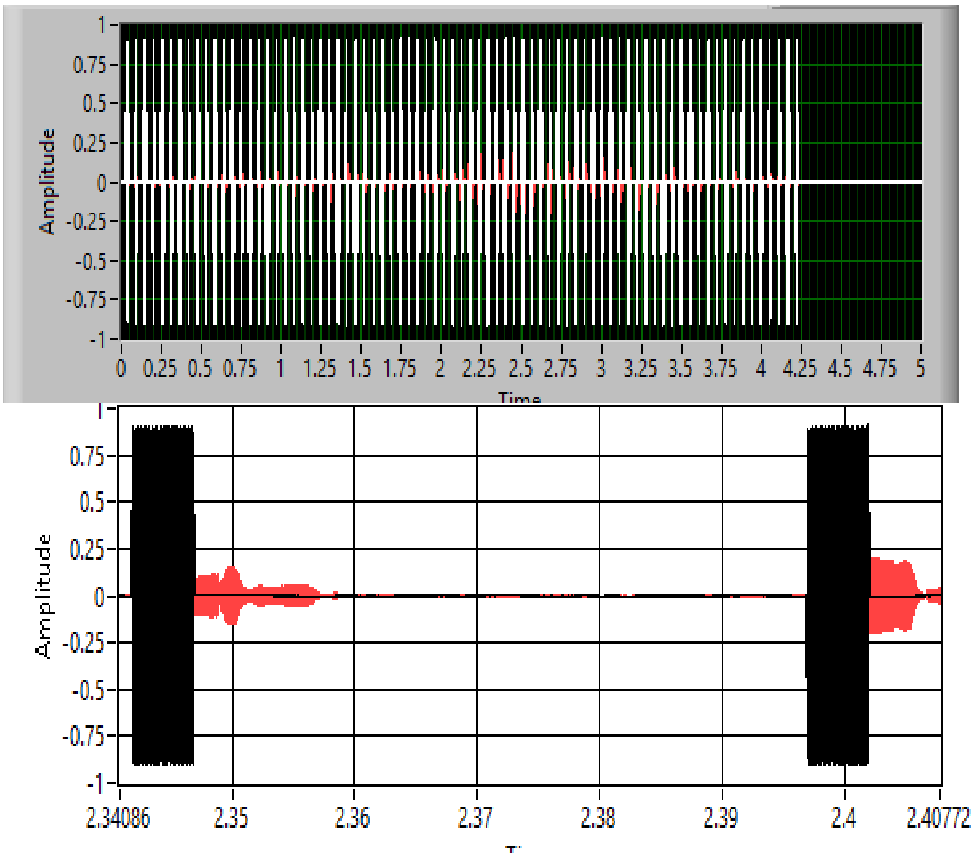


**Figure 15.**Transmitted and received test tank measurement pulse trains.

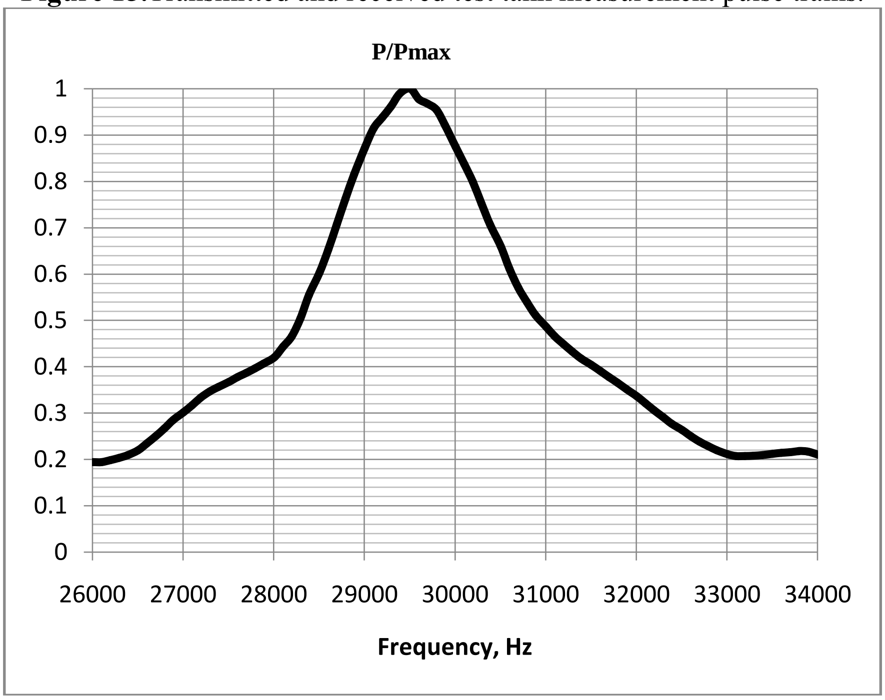


**Figure 16.** Measured sound pressure, normalized to 1 as function of frequency measured in the maximum of antenna pattern.

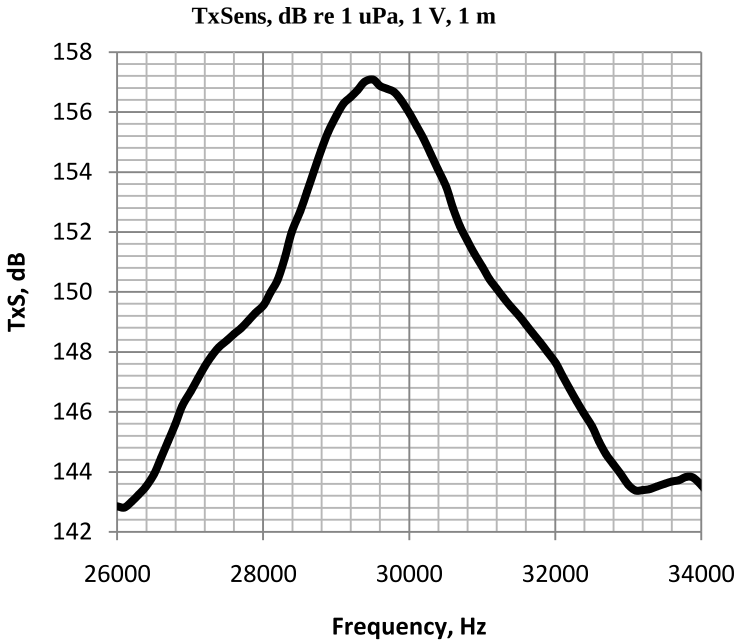


**Figure 17.** Transducer transmitting sensitivity Sv.

## 5. Conclusion

This study aims improving the methodology for test tank impedance and sensitivity measurements of electroacoustic transducers. The following conclusions can be made:

1. Existing methodologies are adapted and developed for measurement of impedance and transmitting sensitivity of electroacoustic transducers.
2. LabVIEW virtual instruments are developed applicable for test tank laboratory equipment measurements with the developed methodologies.
3. Experimental results are presented for impedance and transmitting sensitivity of piezoceramic transducer.
4. Results from the investigations can be used for electroacoustic transducers parameters estimation and in the education.

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