IOP Conf. Series: Earth and Environmental Science **172** (2018) 012021 doi:10.1088/1755-1315/172/1/012021

# Pulse system for evaluation of parameters of electro-acoustic transducers in a hydroacoustic tank

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**Abstract:** In the report an applicationof the pulse method is presented for hydroacoustic test tank measurements. The basic test tank hydroacoustic equipment is from Bruel&Kjaer with National Instruments based control and measurement hardware and software platform. A LabVIEW software is used for synthesis, transmission and measurement of acoustic signals with different pulse lengths and intra-pulse modulations. A number of VI's are designed for digital signal processing and visualization of the signals and results. Capabilities are shown for test tank measurements of sonar transducers pattern and quality factor.

## 1. Introduction.

The basic parameters to be measured for characterization of an electro-acoustic transducer are radiation and reception sensitivities, electroacoustic efficiency, directional characteristics, quality factor Q, and maximum output power. These parameters can be measured in a free from reflections isotropic and uniform underwater space. Several approaches can be used for underwater electroacoustic measurements according to Bobber [1]. They fall in the general category of free-field far-field measurements recommended by the theory. Facilities to ensure this kind of measurements are of various kinds-piers, bridges, barges, or other semi mobile floating structures, and boats or ships. Even this facilities however are far from ideal in providing the conditions assumed by the theory. A true free field or a uniform boundless medium is only an Idealized concept in this case. Even in relatively big facilities there are surface and bottom boundaries contributing reflections, influenced by meteorology changes in the temperature and water boundaries thus preventing accurate measurements and introducing errors in real transducer directivity pattern. Artificial pools and indoor tanks are used also, but they usually require pulsed sound measurement techniques. The basic requirements are: 1) enough space so that interference from boundary reflections can be eliminated by pulsing techniques, anechoic boundaries, or spreading losses due to long distances; 2) a low ambient noise level; and 3) a water medium that is relatively free of anything that will cause refraction and scattering, like currents, temperature gradients, marine life, bubbles, and pollutants. A more satisfactory method of eliminating the effects of reflected waves in measurements is by the use of pulses. Instead of a steady constant waveform (CW) signal, a pulse corresponding to a sinusoidal CW signal of finite duration is emitted.

This pulse reaches the receiver by the direct path before the reflected pulses arrive. If the response of the transducer can be measured in the interval before their arrival, their effect is entirely eliminated. Usually measurements of this kind are made in test tanks which ensures also controllable environment.

## 2. Description of impulse measurement system in a hydroacoustic pool developed in Naval Academy.

The sonar laboratory, developed at Bulgarian Naval Academy under National Science Fund infrastructure project [2] is suitable for transducer parameters measurements using the pulse method. Pulsed measurements are fundamental for characterizing transfer functions of systems and objects in free-field and simulated conditions, which are available in a sonar test tank. [1, 3] It is a common technique for eliminating the effects of reflection (reverberation) from boundaries.

In order to have adequate experimental results it is necessary to do the pulse measurements in a free from reverberation and far for the electroacoustic transducer zone (where the sound wave front is assumed flat in the place of the receiving transducer). The measurement hydrophones are situated in the test tank measurement volume. The parameters of the positioning are as follows: depth – $h$ and distance – $d$ between them. The size of the limiting volume boundaries are: - length $L$ and width $B$ – 'Figure 1'.

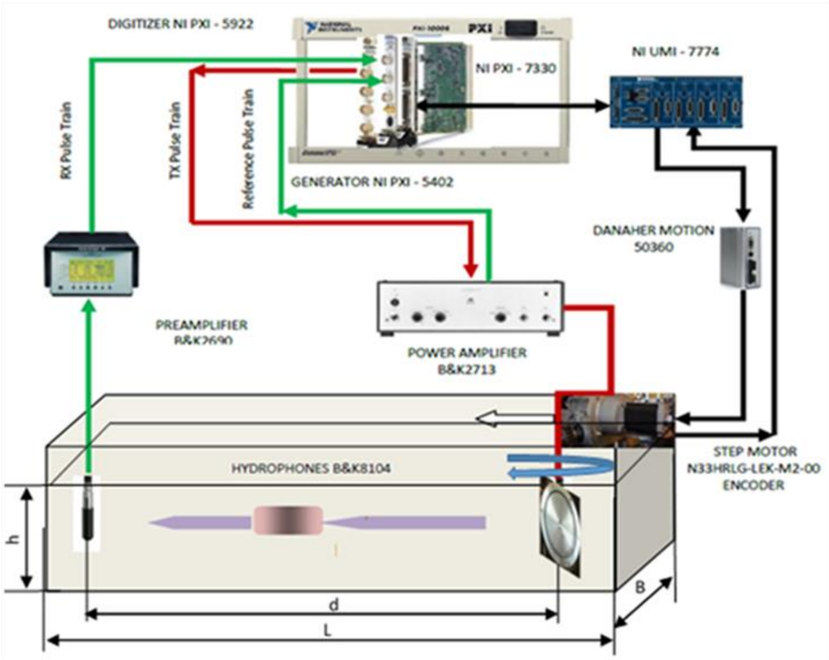


**Figure 1.** Schematics of the test tank pulse experimental setup.

An electroacoustic transducer (projector) is driven with a pulse or short burst CW signal –'Figure 2'. The transmitter and receiver are controlled so that an acoustic signal will be measured only during the short period (gate) of time when the direct projector-to-hydrophone signal pulse impinges on the hydrophone. Pulses arriving prior to this time (like cable crosstalk) and pulses arriving after this time (like reflections from boundaries) are rejected by the receiving system. This "gating" process is necessary for adequate pulse measurements. For far field condition the distance should be [2]:

$$d \geq \frac{a^2}{\lambda} \tag{1}$$

where, $a$ is the biggest dimension of the hydrophone and $\lambda$ is the wave length.

The pulse length or duration τ must be long enough for a steady-state condition of oscillation. The practical criterion for this transient period is that it consists of at least $Q_m$ cycles, where $Q_m$ is the quality factor of the electromechanical system. Rise time (or build up time) of a projector is the time required for a pulse to reach its steady state amplitude, and can be estimated by its:

$$\tau' = \frac{Q_m}{\pi f_0} \tag{2}$$

where $\tau'$ is a time constant, $\tau' = \frac{2L}{R}$ , $L$ - inductance (equivalent mass), $R$ - resistance (damping constant), $f_0$-resonant frequency, $\Delta f$ is -3dB bandwidth.

In order to eliminate influence of reflections during measurements the following conditions should be met for the pulse width:

$$\tau < \frac{2d}{c} \tag{3}$$

to eliminate reflections between transducers;

$$\tau < \frac{L-d}{c} \tag{4}$$

to eliminate reflections from the walls of the test tank and

$$\tau < \frac{\sqrt{x^2+d^2}-d}{c} \tag{5}$$

to eliminate reflections from the water surface.

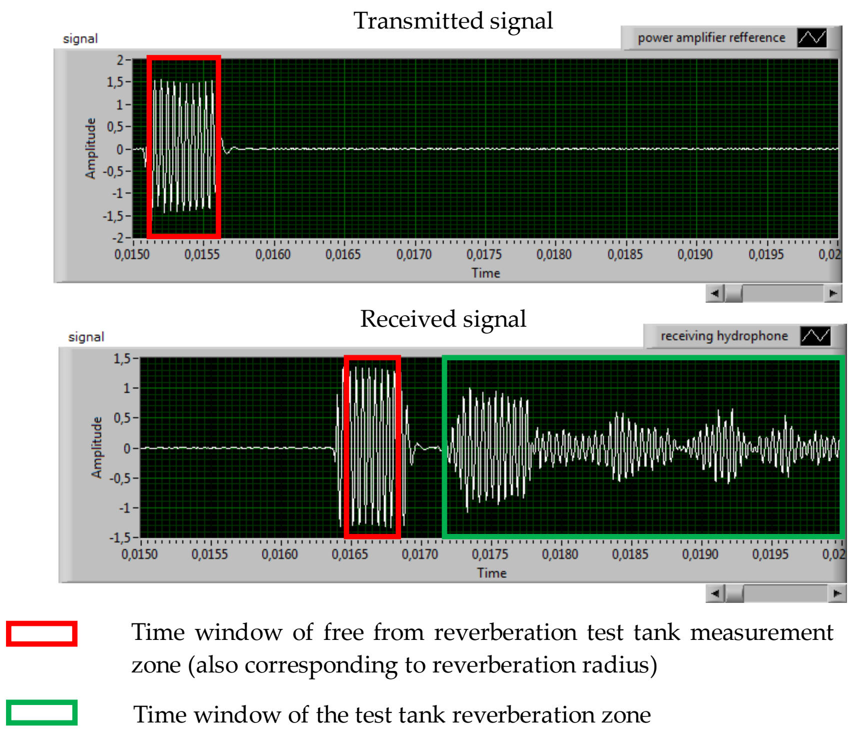


**Figure 2.** Test tank pulse gating measurement principle with direct pulse in red.

## 3. Transducer pattern and *Q* factor measurements.

### *3.1. Theoretical model of a circular transducer radiation.*

The sound pressure of a circular transducer with uniform normal velocity (called a circular piston because of the uniform velocity) in the far field is given with the following expression in cylindrical coordinates [5]:

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$$b(\theta) = \frac{2J_1(ka\sin\theta)}{ka\sin\theta} \tag{6}$$

where $J_1(x)$ is Bessel function of first order, $k$ is the wave number and $a$ is the radius of the transducer.

It must be pointed out that this expression is valid for circular piston vibration in an infinite baffle under constant harmonic mechanical excitation. This is also analytical approximation of the far field acoustical pressure field or for very small vibration displacements of the flat transducer surface. It can be expected that the measured radiated pressure field of a real transducer will be approximated by this function.

*3.2. Experimental results of a circular transducer radiation.*

The pattern of piezoelectric circular piston with diameter of the diaphragm 70 mm is measured. Pulse train signals with frequency 30 *KHz*, width 2 *mS*, pulse repetition period 50 *mS*, transmitted through the water and recorded at the output of the receiving hydrophone are shown on –'Figure3'. [4] The one-tenth of the reference (transmitted) pulse train (red) is sampled at the control output of power amplifier 2710.

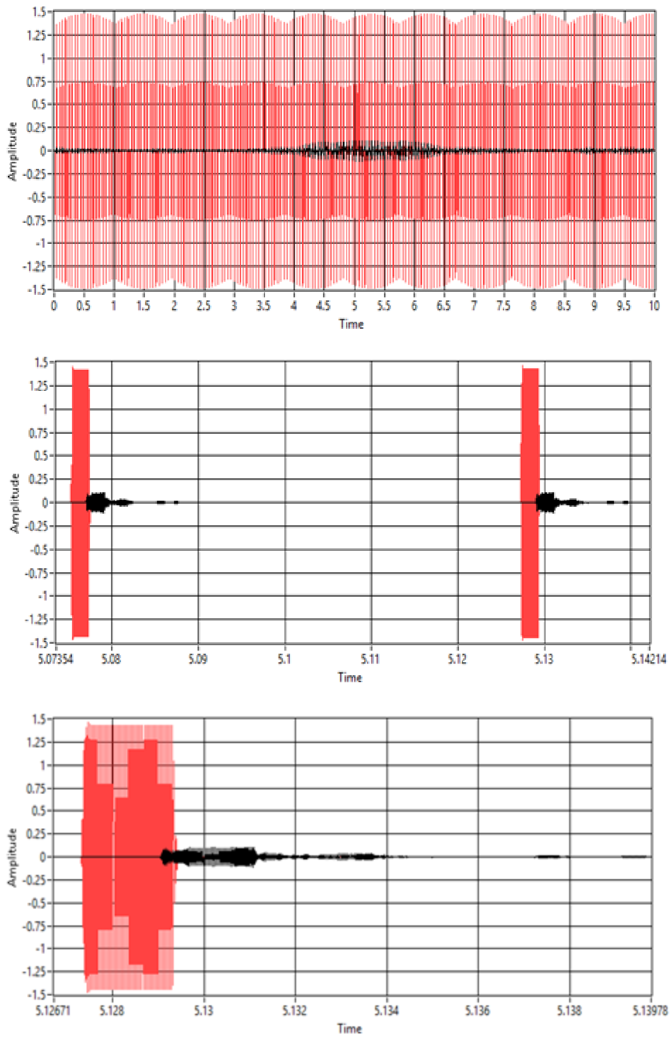


Fig. 3 (a)

Fig. 3 (b)

Fig. 3 (c)

**Figure 3.** Transmitted and received pulse train at frequency 29.5 KHz in 10 s total time interval of full transducer rotation on 360° in 3 different time scales: Fig. 3(a), Fig. 3(b), Fig. 3(c).

The recorded pulse train was preprocessed and measured in LabVIEW and exported in MS Excel where the final pattern was obtained.

Comparison of the normalized measured pressure pattern and theory pattern of the piston transducer, according to expression (6), are shown on – ‘Figure 4’. The received RMS pressure field was measured only for direct signal in time window 0.5 *ms* from the initial direct pulse front to escape from any reverberation.

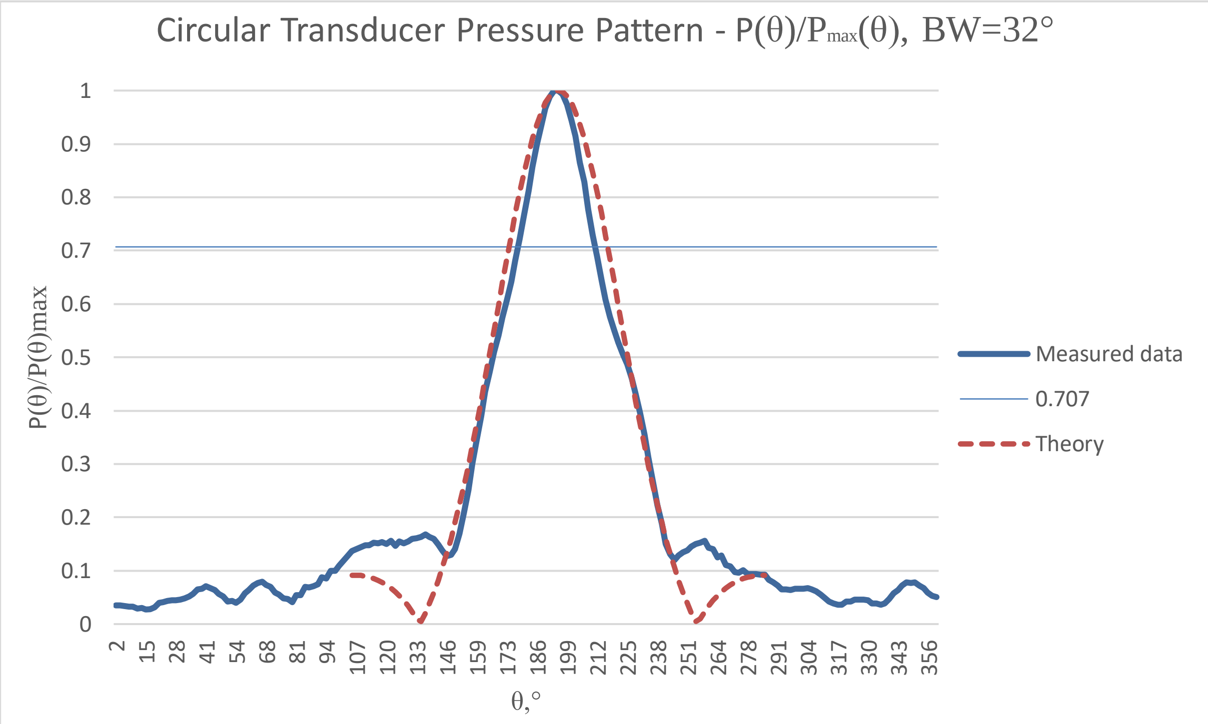


**Figure 4.** Comparison of the normalized measured pressure directivity pattern and theory pattern – expression (6), of the piston transducer at resonance frequency 29.5 KHz.

*3.3. Theoretical model of a transducer Q factor measurement.*

The acoustic transducer with the power cable located in an aquatic environment forms a complex oscillating system that has a qualitative factor *Q*. Measurement of the *Q* factor can be done by using the “ring-down” method or by using its frequency response.

The process of determining the pressure of the transmitted pulse from the transducer is described by the expression:

$$p(t) = p_{max}\left(1 - e^{-\frac{\pi}{TQ}t}\right) \tag{7}$$

where, $T$ – period of transducer own mechanical oscillations;

$p(t)$ - the pressure created by the transducer in an unsettled mode;

$p_{max}$ – the amplitude or maximum pressure created by the transducer system in an established (steady) mode;

The equipment of the acoustic tank allows observation of the increase of the sound pressure level of the oscillations, and counting how many cycles it takes it to rise to the halve of the amplitude. According to formula (7) if the pressure rise to the half amplitude at time *N.T* the expression for the pressure is equal to:

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$$0{,}5p_{max} = p_{max}\left[1 - e^{-\frac{\pi}{TQ}NT}\right] \quad (8)$$

where, $N$ is the number of cycles (periods $T$) it takes the pressure to rise to the half of the amplitude.

From the last expression after conversion the quality factor of the electro-acoustic converter can be found:

$$Q = \frac{\pi}{\ln(2)}N = 4{,}53N \quad (9)$$

This expression is the same as the expression of the “ring-down” method.

A second method to find $Q$ factor is to use the frequency response of the transducer and mathematical approximation such as:

$$Q = \frac{f_o}{f_2 - f_1} \quad (10)$$

where $f_0$ is the resonance frequency, $f_2$ - $f_1$ is the frequency range between the signal’s power is decreased to half the size of the maximum power at resonance frequency.

*3.4. Experimental results of a transducer Q factor measuring.*

The ‘Figure 5’ shows a transmitted pulse from a disc piezo ceramic transducer with 7 cm diameter: the horizontal yellow dense line is the reference level of the amplitude, the dashed yellow line is the half of amplitude rising.

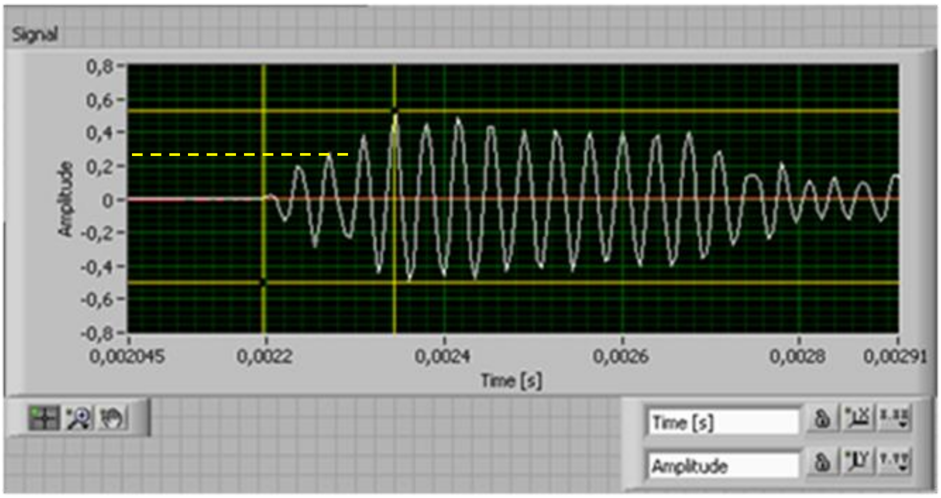


**Figure 5.** Transmitted pulse from disk piezo ceramic transducer with a diameter of 7 cm, pulse length $\tau$ = 0,00046 s and a frequency $f$ = 29,5 KHz.

Here, the transmitted pulse take it 100% reference at $t = 0{,}0023$ *(s)* and we see that it takes about 2 cycles for the amplitude to rise by 50%. Simply by multiplying *2.4,53* we find quality factor $Q \cong 9{,}06$.

The ‘Figure 6’ shows the normalized frequency power response of the transducer measured in test tank with pulse method. The data has exported and processed in Excel.

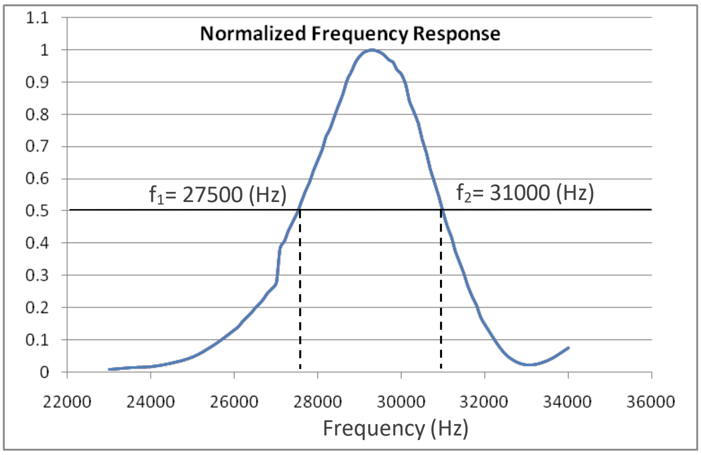


**Figure 6.** The normalized frequency response of the disk piezo ceramic transducer with a diameter of 7 cm.

From the frequency response we find that the resonance frequency of the transducer is 29,5 KHz and -3 dB bandwidth is between 27,5 KHz and 31 KHz. After applying (12), the *Q* factor is obtained:

$$Q = \frac{29500}{31000-27500} = 8,4 \quad (11)$$

## 4. Conclusion.

Based on the B & K and National Instrument equipment and NI's LabVIEW software environment, a system and methodology has been developed to enable the implementation of the impulse measurement method in a hydroacoustic test tank. Virtual instruments have been developed based on this method for measuring the direction diagrams and quality factor of electroacoustic transducers.

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