Hydroacoustic stand for evaluating underwater sound systems in a measurement pool

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Abstract. Measurement of sonar parameters in laboratory conditions is a powerful tool for development, control and diagnostics. The realization of such a tool requires the construction of a measuring pool and its equipment with digital channels for receiving and generating sonar signals. An essential requirement for the measuring equipment is to quantify time and amplitude signals with the necessary accuracy and speed. The paper presents a new stand for evaluating the parameters of active and passive sonar systems. The stand is based on the PXI console of National Instruments and the underwater receiving channel of Bruel & Kjaer. Software solutions for the synthesis, transmission, reception and analysis of acoustic signals with different pulse lengths and intrapulse modulations have been developed through the LabVIEW software platform. VI instruments were developed for digital processing, and visualization of signals, and the ability to measure Sonar Transducer parameters in a test tank.

1. Analysis of the basic requirements for a stand for testing of underwater sound systems

Testing of sonar equipment on a stand makes it considerably easier to evaluate its parameters than to perform similar measurement in real conditions. In order for the results to be reliable and accurate, the measurement conditions must correspond to the actual limitations imposed, the parameters of the measuring apparatus shall allow the generation of test signals with characteristics corresponding to the sonar under test as well as the reception of signals emitted by it. Sonar systems in both versions, passive and active, have been widely used to solve tasks of a different nature both in the water and in the air. Underwater active sonars are the main means of detecting and classifying underwater objects as well as conducting hydrographic measurements. The range of these measurements includes bottom mapping, bottom bathymetry, determination of sound wave velocity, salinity, temperature and velocity of water layers. In the air, active sonars are used for ultrasonic distance measurements, car parktronic, ultrasonic echography, defectoscopy, and in other applications. Passive sonars have found a broad application for detecting underwater objects through their noise and measuring its parameters (intensity, bandwidth, spectral lines, spectral level, and correlation time). In these systems, the measurement of object parameters, distance, bearing, radial velocity, and own noise is performed by evaluating the parameters of the received signal. The range of these parameters includes amplitude, latency, Doppler Frequency, Strength, Spectrum, and Spectral Lines in the Spectrum. To measure these parameters, testing systems must support narrowband processing techniques for active systems and broadband processing for passive systems. To limit the impact of external disturbances, it is required that measurement is performed in a test tank for underwater sonar systems or in anechoic chambers for air sound systems.
The main modules of the presented stand include a test tank, a microprocessor unit, electroacoustic transducers, a calibrated input amplifier and an output power amplifier. For non-distortion measurements in a test tank a far field condition between hydrophones must be met [1, 2].

\[ d \geq \frac{a^2}{\lambda}, \]  

where \( a \) is the biggest dimension of the hydrophone and \( \lambda \) is the wave length; \( d \) is the separation between hydrophones.

Also the pulse length \( \tau \) must be long enough for a steady-state condition of oscillation to be met [3] and the spectrum of signal must be enough to eliminate the impact of reflections from the water boundaries [4, 5].

The microprocessor block is used to perform the following functions:

- Control the stand operating modes;
- Receive and convert the analog signal into a digital form;
- Analysis of an active sonar signal or underwater object noise in the received input signal mixture;
- Synthesis of signal with duration and frequency band corresponding to the signal of the tested system.

The microprocessor system uses the Direct Digital Synthesis (DDS) technique to generate test signals. This technique requires the rapid processing of the microprocessor system to meet the condition:

\[ f_s \geq f_0 N, \]  

where \( f_s \) is frequency of the microprocessor system; \( f_0 \) – signal frequency; \( N \) – number of samples to generate signal.

For periodic signal synthesis, DDS generators use a table with digital signal values for one period (LookUp Table – LUT). To generate the sinusoidal signal values with the LUT table, the following formula is used:

\[ U(n) = \sin \left( n \frac{360}{N} K \right) + U_0, \]  

where \( n \) is a sample number from 0 to \( N \); \( K \) – number of DAC quantum levels; \( U_0 \) – the DC voltage generated at the output of the DAC.

The number of samples in the LUT table \( N \) is determined by the expression:

\[ N = \frac{f_s}{f_0} \]  

2. Functional description of a hydroacoustic stand for tests of underwater sound systems

The input amplifier provides the necessary sensitivity of the receiving channel. The basic requirements for it are to be calibrated and matched with the receiving hydrophone, to have bandwidth equal to the bandwidth of the test signal, to provide the required amplification factor, and not to cause nonlinear signal distortion. The power amplifier provides the power for transmission of test signals in the measuring pool. Its basic requirements are to be impedance matched with the acoustic transducer, its frequency band to permit the transmission of the test signals and to have calibrated power output.

The described stand is designed to study the operation of an underwater sound sonar simulator and measure the parameters of electro-acoustic transducers. The stand is built on the hardware of Bruel & Kjaer and National Instruments and NI LabVIEW software. The stand uses the 8100 and 8104 hydrophones with a bandwidth of up to 100 kHz, the NEXUS type 2692 Bruel & Kjaer's wideband two-channel pre-amplifier for calibrated amplification of the received signals. For power amplification of the emitted signals, a type 2713 Bruel & Kjaer amplifier is used with a maximum power of 100 W. The computer analysis, synthesis and display block is based on National Instruments digital units including PXI console, PXI high-speed digitizer type NI 5922 and PXI signal generator type NI 5402. They allow
for the input of 6 MHz bandwidth signals and synthesis of signals with a bandwidth of up to 20 MHz. The functional diagram of the stand is shown in figure 1.

2.1. Functional description of the hydroacoustic stand
Functionally, a generator, receiving and control channels are implemented in the stand. The generator channel produces and emits the test signals (continuous or pulsed, with or without modulation) for analysis of the input stages of the test apparatus or for evaluation of the antenna electroacoustic parameters. The receiving channel handles both broadband and narrowband signals. The use of high-speed ADC NI 5922 and digital signal processing ensures high stability of the spectral estimation [6] and accuracy of power spectral measurements [7]. The stand also allows for measurement of the sensitivity and level of emission of an electroacoustic transducer.

2.2. Measurement methodology for transmitting sensitivity of an electroacoustic transducer.
Functional diagram of the transducer transmitting sensitivity measurement stand is presented in figure 2. The green lines show electrical input to industrial PXI system from power amplifier and preamplifier while the red lines show transducer stimulus signal to the power amplifier.

Important parameters of an electroacoustic transducer are his receiving and transmitting sensitivities. The receiving sensitivity is [8-10]:

\[ S_H = \frac{e}{p}, \]  

where \( e \) is the effective electrical voltage at its output, \( V \); \( p \) – 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:

\[ S_V = \frac{p}{E}, \]  

where \( E \) is the electrical voltage at the input of the transducer, \( V \); \( p \) – the acoustic pressure at distance 1 m from the transducer, Pa.

Figure 1. Functional scheme of hydroacoustic stand.
Figure 2. Test tank experimental setup for measurement of transmitting sensitivity.

The required dimension of the transmitting sensitivity is dB re V/μPa at a distance of 1 m from the transducer. The experimental study of the transducer transmitting sensitivity allows for its performance to be estimated as a function of frequency.

The unknown transmitting sensitivity of an electroacoustic transducer is measured with relative calibration by the comparison method [11, 12]. The pressure at distance $d$ from the transducer is measured with previously calibrated hydrophone. If an effective voltage $E$ is applied at the transducer with transmitting sensitivity $S_V$, the sound pressure at distance $d$ will be:

$$p = \frac{E S_V}{d}.$$  \hspace{1cm} (7)

In expression (6) it is assumed that a spherical wave is transmitted from the transducer and its effective pressure $p$ is measured at a relatively far distance $d$. It is known that for radiated sphere wavefront the pressure at distance $d$ will be $d$ times smaller (inverse proportion) than the pressure at distance of 1 m from the transducer which is $S_V$. From (5) and (7) it follows that the unknown transmitting sensitivity is:

$$S_V = \frac{dp}{E} = \frac{de}{ES_H}.$$  \hspace{1cm} (8)

In logarithmic units expression (8) is:

$$20 \log_{10} S_V = -20 \log_{10} E - 20 \log_{10} S_H + 20 \log_{10} d + 20 \log_{10} e.$$  \hspace{1cm} (9)

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

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 through LabVIEW motion interface and is precisely measured. The control of the emitted pulses is done through the LabVIEW virtual instrument, figure 3. In order to estimate the quality of the assumption that an impulsive sound field may have sphere wavefront according to (7) 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.
Figure 3. Front panel of virtual instrument for estimation of test tank pulse signals SPL.

Transmitted pulses have a pulse width of 0.5 ms. The 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 4.

Figure 4. Comparison between measured SPL (MSPL) and theory SPL (TSPL) for spherical wave front at different distances from the transducer BK8104.

2.3. Experimental results.

The paper presents the results of two experiments. The first is a microprocessor system test built with the “Arduino Due” microcontroller, which is designed to detect an active sonar pulse and to synthesize an echo signal with a duration and frequency corresponding to the sounding pulse. For this purpose, the stand is programmed to work with a test algorithm in the presented sequence in figure 5. The test pulse signal is synthesized by a DDS generator operating in arbitrary mode. A time selective window is used to eliminate reflections and spectral leakage. The time domain and spectral diagrams of the test (sonar) and echo signals are shown in figures 6 and 7.
Figure 5. Algorithm and virtual instruments use for testing a Hydroacoustic signal imitators.

Figure 6. Pulse signals with frequency 6.4 kHz and duration $t = 470$ ms.

Figure 7. Spectrum of received pulse signals (Sonar and Echo) at a frequency of 6.4 kHz and duration of $t = 470$ ms.

The second experiment demonstrates the possibilities of hydrophone sensitivity measurement at the stand. Comparison of measured transmitting sensitivity of BK8100 hydrophone compared with data from BK nomogram is given in figure 8.

The experimental results for the transmitting sensitivity of the broadband transducer are presented in figures 9 and 10.
Figure 8. Measured transmitting sensitivity of BK 8100 hydrophone.

Figure 9. Pulse train of 2 ms transmitted from a broadband transducer and received with the calibrated hydrophone channel with incremental frequency from pulse to pulse.

Figure 10. Measured transmitting sensitivity of a broadband transducer “BII-8080”. 
3. Conclusion
The demonstrated Stand is built up through LabVIEW sequenced development software modules that allow for the hardware to be configured in order to perform various measurements. Thanks to the built-in libraries for DDS functional generator and ADC, the transducer generates sound signals with and without modulation, and allows for the development of digital processing algorithms in the interest of highly accurate measurements. A methodology for test stand sonar transducer transmitting sensitivity measurement is presented based on software gating procedure. Broadband sonar imitator transducer transmitting sensitivity is measured with the stand in the test tank.

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