TRANSMISSION OF DIGITAL SIGNALS IN A NONSTATIONARY HYDROACOUSTIC CHANNEL

IWONA KOCHAŃSKA, HENRYK LASOTA,
ROMUALD MAZUREK, JAROSŁAW ADAMCZYK

Gdańsk University of Technology
Faculty of Electronic Engineering, Telecommunications and Computer Science,
Department of Marine Electronic Systems
ul. G. Narutowicza 11/12, 80 952 Gdańsk
iwona.kochanska@eti.pg.gda.pl, henryk.lasota@ eti.pg.gda.pl
romuald.mazurek@eti.pg.gda.pl, jaroslaw.adamczyk@eti.pg.gda.pl

From the communication point of view, transmission performances of a hydroacoustic channel are strongly limited due to multiple reflections of sound waves on the bottom and water surface, and to the nonstationarity caused mainly by water surface movement. This article presents a model of channel transmission properties which introduces nonstationarity to the channel impulse responses by assuming random variability of arrival times and amplitudes of subsequent elements of the impulse response. Transmission properties of this kind of channel have been tested in a digital simulator, using binary PSK and FSK signals. The results indicate that transmission velocity in such channels is reduced.

INTRODUCTION

Wireless transmission channels are nonstationary. Wave propagation conditions, for both radio and acoustic waves, are changing in the natural environment for many reasons. In radio transmission, channel impulse response measurements are used during transmission which enable to utilize adaptational techniques of eliminating the influence of reflections on detection quality. However, in a hydroacoustic channel, rapid changes of transmission conditions make it impossible to directly transfer to underwater communication the techniques and devices which resulted in perfect efficiency of digital transmission.

The approach proposed in this article represents an attempt to model the variability of conditions prevailing in a real hydroacoustic channel. Acoustic signals transmitted in a shallow underwater channel reflect on the bottom and water surface. The reflected signal represents a significant part of the signal energy reaching the receiver[1]. A simulation of digital signal transmission through the channel was performed, assuming first stationary reflections (static water surface), and then nonstationary reflections (disturbed water surface). Binary pseudorandom sequence was used in test signals with FSK and PSK modulation.

1. CHANNEL WITH REFLECTIONS

The efforts aimed at building a model of transmission properties of a hydroacoustic channel focused on elements affecting the variability of impulse response in time. It was therefore assumed that the propagation medium was lossless, the aqueous environment uniform and constant in time, the wave propagated spherically, and the only influence of medium boundaries consisted in reflections. It was also assumed that the water surface was a pressure-release boundary, and the bottom was perfectly hard, which means that acoustic wave reflection coefficients for water surface and bottom equaled -1 and +1, respectively [1].

At the first stage it was assumed that water surface was still. The reflected signals have a predefined amplitude and reach the receiver with a constant delay relative to the time of transmission. The impulse response *h(t)* of such a channel, based on the arrival of direct wave, can be expressed as (1):

$$h(t) = \delta(t - t_0) + a_1\delta(t - (t_0 + t_1)) + a_2\delta(t - (t_0 + t_2)) + \ldots + a_n\delta(t - (t_0 + t_n)) \qquad (1)$$

where: $\delta(t)$ - Dirac delta function,

t_0 - time of direct wave arrival to the receiver,

t_i - delay of reflected waves relative to direct wave.

Amplitude coefficients a_i represent propagation losses of the spherical wave. These are inversely proportional to propagation times of subsequent reflected waves. Their signs depend on the number of reflections on water surface. Negative values are used for odd numbers, positive values are used for even numbers of reflections:

$$a_i = \pm \frac{t_0}{t_0 + t_i} \qquad (2)$$

A natural digital model of the channel described by (1) is discrete FIR filter with a given number of non-zero coefficients representing the direct wave and reflected waves reaching the receiver. Distances between non-zero lines of the filter represent the delays of reflected waves reaching the receiver. The values of filter coefficients represent amplitudes of the reflected waves.

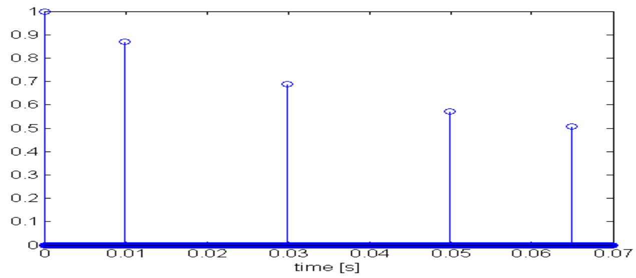

Fig. 1. Normalized impulse response of a channel with four reflections with delays: $t_1 = 10ms$, $t_2 = 30ms$, $t_3 = 50ms$, $t_4 = 65ms$.

Figure 1 presents a sample impulse response of a channel with four reflections which reach the receiver with the following delays: $t_1 = 10ms$, $t_2 = 30ms$, $t_3 = 50ms$ and $t_4 = 65ms$ relative to the direct wave. Figures 2 and 3 show a Gaussian pulse of 10kHz carrier frequency, on the channel input and output, respectively. Figures 4 and 5 present the normalized amplitude spectrum of this pulse, initial and after transmission through the channel, respectively.

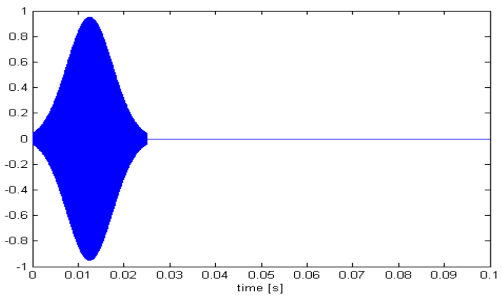

Fig. 2. Gaussian pulse, 10 kHz, 25 ms.

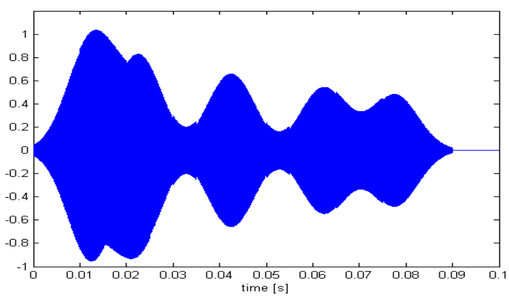

Fig. 3. The pulse shown in Figure 2 after transmission through the channel from Fig.1.

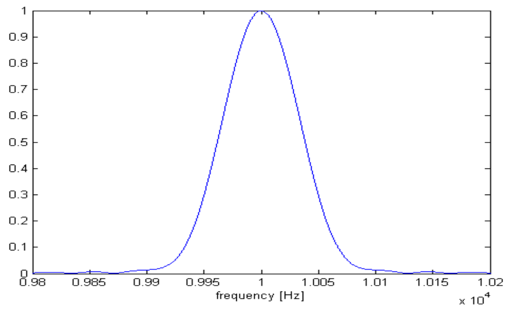

Fig. 4. Normalized amplitude spectrum of the Gaussian pulse shown in Fig. 2.

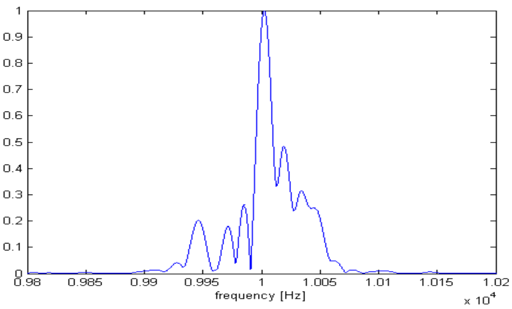

Fig. 5. Normalized amplitude spectrum of the signal shown in Fig. 3

2. MODEL OF A NONSTATIONARY CHANNEL

To model the nonstationarity of a real channel, amplitudes and delays were introduced in the impulse response (1) as follows:

$$h(t) = \delta\left(t - t_0\right) + a_1 b_1(t)\delta\left(t - (t_0 + t_1 + c_1(t)\right) + \ldots + a_n b_n(t)\delta\left(t - (t_0 + t_n + c_n(t)\right) \tag{3}$$

where $b_i(t)$ and $c_i(t)$ are the variation functions of the amplitudes and the delays of reflected signal i, respectively. For the sake of simplicity, the model assumes that they are harmonic functions, supposing intuitively that this somehow reflects the influence of water surface waves on the amplitudes and delay times of subsequent acoustic wave reflections. It was assumed that the frequency and amplitude of these variations are random, separately for each reflection:

$$b_i(t) = B_i \cos^2(\omega_{ai} t + \varphi_{ai}) + (1 - B_i) \tag{4}$$

$$c_i(t) = \pm C_i \cos(\omega_{di} t + \varphi_{di}) \tag{5}$$

where: B_i, C_i - amplitude variations randomly selected from a given range,

ω_{ai}, ω_{di} - random pulsations of, respectively, amplitude and delay time variations,

$\varphi_{ai}, \omega_{di}$ - random initial phases of the above variation functions.

Calculation of impulse response of a nonstationary channel is performed in the same way as for the stationary channel – using the discrete FIR filter with a given number of non-zero coefficients. This time, the response changes in subsequent moments of time. The number of response lines remains unchanged; their position on the time axis is changing. We assume that the first response line, representing the direct wave, has a constant position on the time axis, and a constant value. Reflections are represented by lines whose value and delay relative to the direct signal change in time, according to the harmonic functions mentioned above.

Before launching the simulation, the number of reflections is specified as well as the impulse response observation time window, random values and the signs of reflection coefficients. The initial positions of non-zero lines, which are subject to harmonic deviations with random frequency, are also fixed.

Figure 6 presents a response of a nonstationary channel with 4 reflections to a 25 ms Gaussian pulse. The amplitude spectrum of the pulse changed by this channel is presented in Figure 7.

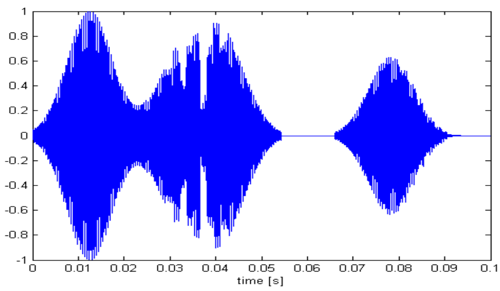

Fig. 6. Response of a nonstationary channel to the 25 ms, 10kHz Gaussian pulse. Channel parameters: 4 reflections, response duration 70 ms, sampling frequency 32kHz.

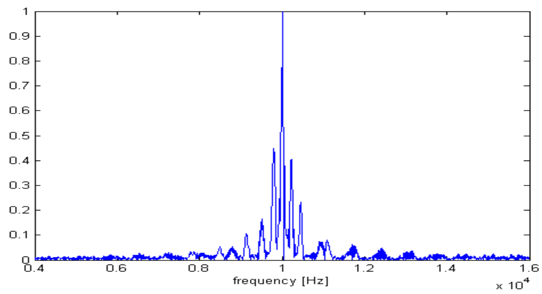

Fig. 7. Normalized amplitude spectrum of the pulse shown in Fig. 6

3. TESTING PROPERTIES OF A CHANNEL

Influence of the modeled channel on the transmission possibilities of binary signals has been examined. Two modulation schemes of continuous carrying wave has been used, namely frequency shift keying (FSK) and phase shift keying (PSK). The simulation of digital signal transmission has been performed in the Simulink computing environment of The Mathworks. The input signal was a pseudorandom binary series generated with a specified transmission rate. Models of modulator and demodulator has been taken from the Communications Blockset. The channel was implemented as a user functional Block [5].

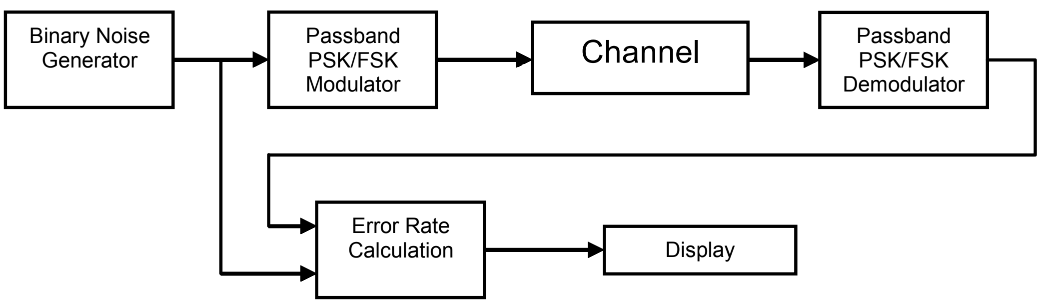

Fig. 8. Transmission simulator block diagram

The result of the simulation was bit error rate (BER) of received signal. A diagram of the transmission model is presented in Fig. 8.The Binary Noise Generator Block generates random binary numbers. The PSK/FSK Modulator Passband Block modulates signal using the phase/frequency shift keying method. The PSK/FSK Demodulator Passband Block demodulates the received signal using the appropriate method. The Error Rate Calculation Block computes the BER of the received data. The Display Block shows the value of the BER [4]. Parameters of the simulation system are presented in Table 1.

Tab.1 Parameters of the simulation

parameter	**Value**
modulating signal	pseudorandom binary signal
distance between transmitter and receiver	1000 m (667 ms)
sampling frequency	16 kHz
carrier frequency	5 kHz
frequency separation for FSK modulation	800 Hz

Tab.2 Results for a stationary channel (4 reflections)

Transmission rate [b/s]	**10**	**15**	**30**	**50**	**100**
BER [%]- FSK modulation	0	0	17	22	34
BER [%]- PSK modulation	0	0	0	25	32

The simulation results for the stationary channel are presented in Table 2. The tests have been made for five different transmission rates from the range of 10 b/s to 100 b/s. In the case of FSK modulation, there were no errors in the received signals for the rates lower than 30 b/s. For the faster rates the BER suddenly started to gain high values, increasing from 17% for 30 b/s up to 34% for 100b/s rate. In the case of PSK modulation scheme, the bit rate limit value, for which the BER was still equal to zero was lower. Significant errors, detected in 25% of the data, appeared for 50 b/s rate. Higher values of BER for the FSK modulation are somehow surprising. It can be explained as a result of the comb filtering properties of the channel (Fig 7).

Tab.3 Results for a nonstationary channel (4 reflections)

Transmission rate [b/s]	**10**	**15**	**20**	**50**	**100**
BER [%]- FSK modulation	<0.1	0.15	0.6	2.0	6.2
BER [%]- PSK modulation	<0.1	0.3	0.8	4.8	11.6

The tests made for nonstationary channel have shown, that determining the limit values of the errorless transmission rates is not possible. The results of the simulation, which also has been made for rates in range of 10 b/s to 100 b/s, are presented in Table 3. The error rate increases monotonically with the increase of the transmission rate, although slower than in the stationary channel. In this case, values of BER obtained for FSK modulation are lower than for PSK.

4. CONCLUSION

The model of a nonstationary, highly variable transmission channel, utilizing the concept of a discrete FIR filter, presented in this article, should be regarded as a starting point for building a model which would reflect better the real hydroacoustic channel. The idea of nonstationary channel should be developed, the harmonic changes of impulse response being a first approach, related in some manner the water surface movements. Transmission tests of channel models should result in finding qualitative and quantitative relationships between the variability of impulse response parameters of the channel and digital transmission rates, depending on modulation schemes, coding, and detection techniques applied.

REFERENCES

[1] C. S. Clay, H. Medwin, “Acoustical oceanography: principles and applications”, John Willey & Sons Ltd, , New York 1977.

[2] H. G. Urban, “Handbook of Underwater Acoustic Engineering”, STN ATLAS Elektronik GmbH, p.77- p.83, Bremen 2002

[3] A.D.Waite, “Sonar for Practising Engineers”, John Willey & Sons Ltd, p.43 – p.67, England 1998.

[4] The Mathworks Communications Toolbox Documentation http://www.mathworks.com/access/helpdesk/help/toolbox/commblks/commblks.shtml

[5] The Mathworks Matlab Documentation http://www.mathworks.com/access/helpdesk/help/toolbox/simulink/simulink.shtml