APPLICATION OF CDMA MODULATED SIGNALS IN SEAFLOOR REMOTE SENSING

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The paper investigates the application of digital modulation access technique called Code Division Multiple Access (CDMA) to remote sensing of a seafloor. In a traditional sonar, the next ping cannot be sent until the echo from previous transmission has been received by the sonar transducer. As a result, such a sonar system is characterized by low duty ratio what causes the decrease of data resolution especially for larger depths. Using the CDMA modulation technique, may reduce pulse repetition rate. In the CDMA technique, each sonar pulse consists of several multiple narrow pulses, where each is encoded with a phase shift 0 or π based on a spreading code. The paper presents the performance investigation results for this modulation scheme as applied both to transmitted and seafloor backscattered signal. The bottom backscattering was modeled numerically for typical bottom material and morphology. The advantages and constraints of the proposed technique were discussed in the context of echo detection and usefulness in acoustic seafloor characterization.

INTRODUCTION

The paper examines the performance of the spread spectrum (SS) transmission method called CDMA as applied to single beam echosounder, where each ping is transmitted over N narrow time slots. Each slot (called chip) transmits an echosounder impulse encoded with a 0 or π phase spread direct sequence code offset. First of all this method can be used for a precise bottom echo localization in a strong interference environment, where echoes from previous transmission overlap current echoes. Another application of the method is a deep water surveying. Usually a long ping duration cycle impacts a low cross tracking resolution of bathymetric measurements in such a cases. The SS application can improve the performance the sonar system, including better interference rejection. Both improvements are consequences of Shannon theory [1].

The main encouragement in the presented research, were permissible results achieved in the field of spread spectrum design in other disciplines viz. communication [2], [3], [4]. Moreover, in [5], [6] it is shown that a complex transmission signals like chirp signals applied to an echosounder transmission ping can improve bottom detection and sub bottom layers resolution. Additionally, an acoustic sensing of seafloor can be described as a channel with an impulse response similar to low pass filter. This is the base assumption in researches of [3], [7]. The latest achievements in broadband transducers were taken into account as well.

The spread spectrum systems were released for acoustic localization purpose, where acoustic signals have to be received from a few sources simultaneously [1]. The above-mentioned works show at first very good noise and interference resistance.

1. SPREAD SPECTRUM

Spread spectrum refers to a number of coding methods that convert a relatively narrow-band signal into a wide-band signal with a much lower power density. The two main classes of SS communications systems are frequency hopping (FH) and direct-sequence (DS) systems [1]. DS SS systems use a spreading carrier frequency, instead of direct modulation the data signal by a higher-rate pseudo-noise (PN) sequence. This effectively spreads the bandwidth by the ratio of the PN bit rate to the data bit rate. Demodulation is performed at the receiver by generating an estimate of the PN sequence and using this to demodulate each chip. PN sequences are binary sequences that exhibit noise like randomness properties. The definition of randomness was studied by Golomb and requires some properties presented in [1]. In this class of sequences, there are Gold codes sequences and special Barkers codes with a minimum autocorrelation sidelobe, which was studied in the described experiment.

The crucial role in the SS method plays the receiver and especially the crosscorrelator shown as a consequent block, after analog digital converter (*ADC*), in the processing flow diagram in Fig.1. In Fig. 2, a detailed correlator block diagram is presented. The correlation C_k, for a *k-symbol* shift of an *N-bit* code sequence $\{X_j\}$, is given by

$$C_k = \sum_{j=1}^{N-k} X_j X_{j+k}$$

where X_j is an individual code symbol taking values +1 or -1 for $j=1, 2, 3, \ldots, N$.

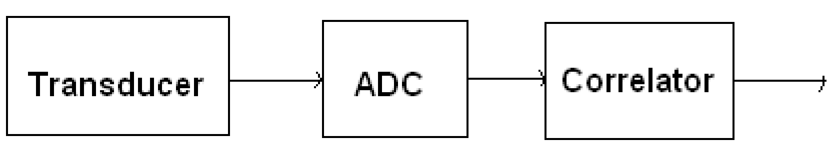

Fig.1 Spread spectrum receiver block diagram

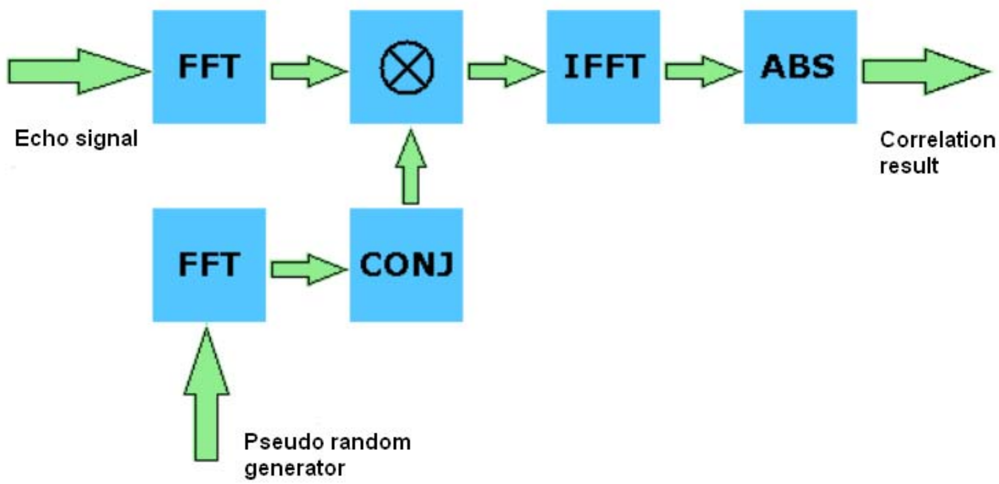

Fig.2 The applied pseudo random correlator algorithm

The mathematic formulae of presented algorithm is:

$$z(n) = IFFT\left(DFT(x(n)) \cdot \overline{DFT(h(n))}\right), \qquad (1)$$

2. TRANSMITTED SIGNAL

In the experiment three types of signal were used: a regular pulse, Barker code and Gold code, as shown in Figs.5, 7, 9. Due to the mentioned frequency constraints of the transducer, the envelope shape of transmitted was assumed, as shown in Fig.3. The carrier frequency was set to $f_0 = 35$ *[kHz]*, the pulse duration was $T = 2$ [ms]. The time constant *tau* for the rise and decay part of the envelope was set to $5^* T_0, T_0 = 1 / f0$. Sampling rate was set to $fpr = 1MHz$.

The pulse of a spread spectrum transmission shown in Fig.7 and Fig. 9 had the following parameters: pulse carrier frequency was set to $f_0 = 35$ *[kHz]*, a pulse duration $T = 0.02$ *[s]*, and time constant *tau* for rise and decay part of envelope the same as above.

The generated pseudo random signal was composed of a sequence of the signals described above, with the shift of 0 or π depending on the sequence element sign, as shown in Figs.5, 7, 9. The assumed signal parameters assure the maximum bandwidth of transmitted signal not to exceeds 90kHz.

3. BACKSCATTERING MODEL DESCRIPTION

The modeling of acoustic wave scattering on seabed surface is based on the BORIS model [3]. In this model, assuming that the source transmits a signal $p_{tr}(t) = p_0 s(t)$ downwards towards the seabed (Fig. 2), the echo $p(t)$ from the bottom scattering 2^D surface is calculated as:

$$p(t) = a \iint_S \frac{\cos[\gamma(\mathbf{R})] b^2(\mathbf{R})}{R^2} s'\left(t - \frac{2R}{c_0}\right) dS, \qquad (2)$$

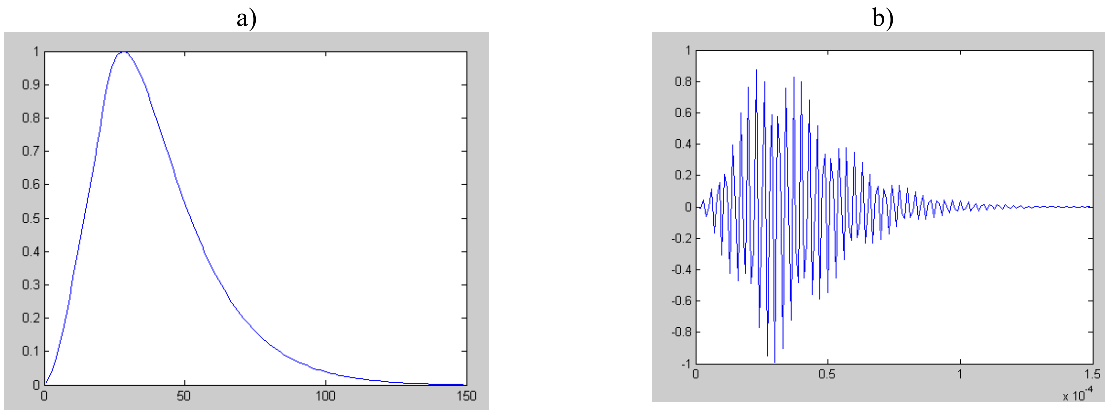

Fig.3 Base envelope shape (a) and carrier multiplied by the envelope of the particular impulse transmitted by echosounder used in pseudo random spread chip sequences

where $a = p_0 \Re_r / (2\pi c_0)$, p_0 is the transmitted wave pressure amplitude, $\Re_r$ – the plane wave reflection coefficient for water-bottom interface, c_0 - sound speed in water, **R** – the vector from the transducer to surface element *dS*, *R* – the length of **R**, γ - the incident angle, *b* – the beampattern value for element *dS* of the insonified bottom surface *S*, assumed to be the same for transmitting and receiving, and *s*'(*t*) - first time derivative of transmitted signal *s*(*t*).

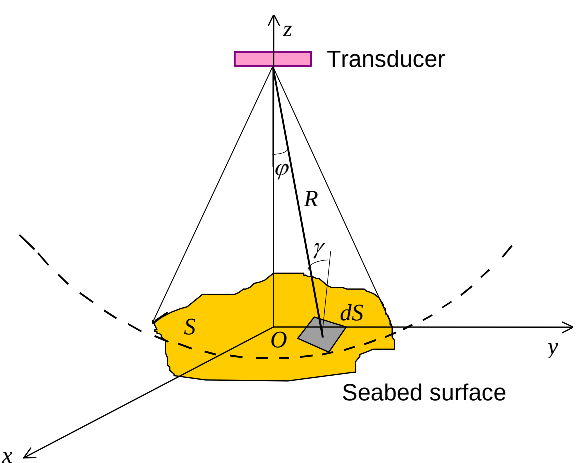

Fig.4 Geometry used in BORIS model for calculation of seabed surface scattering echo

4. RESULTS

The results consist of comparison of conventional pulse sent/received and a direct sequence spread spectrum technique. An autocorrelation function was applied directly to high frequency signal. For all cases bottom depth was 90 meters.

For the purpose of comparison, all signal processing techniques were applied for the regular pulse time length. The results, rather predictable were shown in Fig. 5 and Fig. 6. The first one presents the ping shape, next its bandwidth and autocorrelation. The second one presents the same processing technique results applied to the resulting echo. The Fig.6c shows that, though the maximum of the cross correlation is obvious, the echo cannot be identified. That means that almost every cross correlation maximum peak may be used for the echo from the bottom detection.

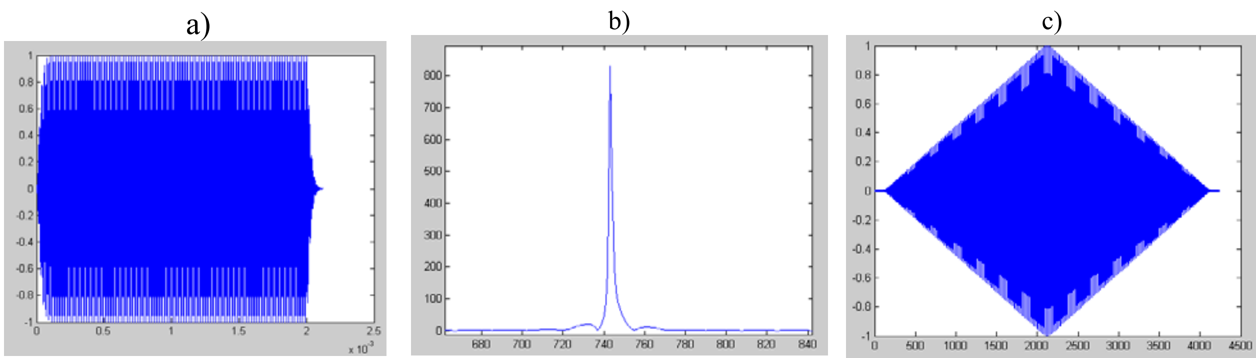

Fig.5 Transmitted signal (a), transmitted signal in frequency domain (15 kHz) (b) and autocorrelation of transmitted signal for Barker code (c)

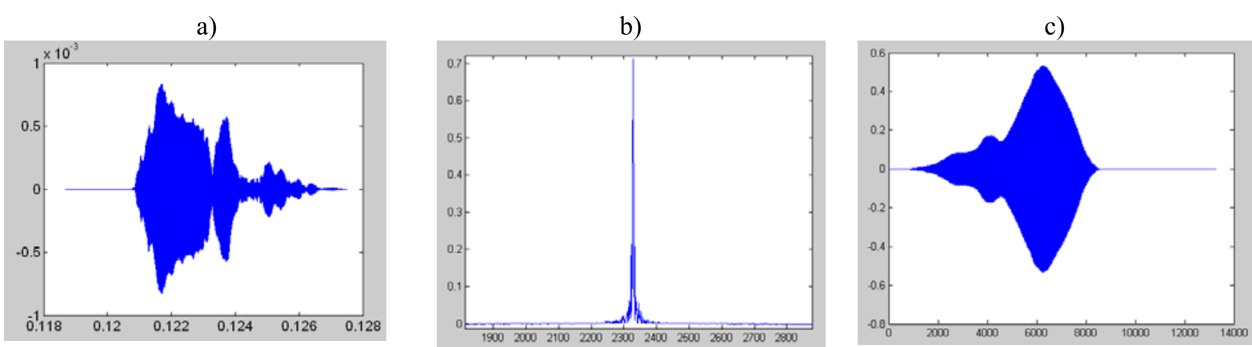

Fig.6 Backscattered signal (a), backscattered signal in frequency domain (12 kHz) (b) and cross correlation of echo with transmitted signal (c)

In Fig 7 and Fig. 8, pulse shape, bandwidth and autocorrelation for signal of short thirteen element Barker codes is presented. The code has following sequence [-1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1]. The -1 means the signal on carrier with a phase shift moved of π. In Fig. 8c, autocorrelation is identified in a simple manner, while comparing this result to Fig. 6c, significantly better amplitude difference was achieved. Moreover, the bottom echo can be localized better now with the pseudo random sequence. Barker codes, which are subsets of PN sequences, are commonly used for frame synchronization in digital communication systems. Barker codes have length at most 13 and have low correlation sidelobes, presented in Fig. 7c.

a) b) c)

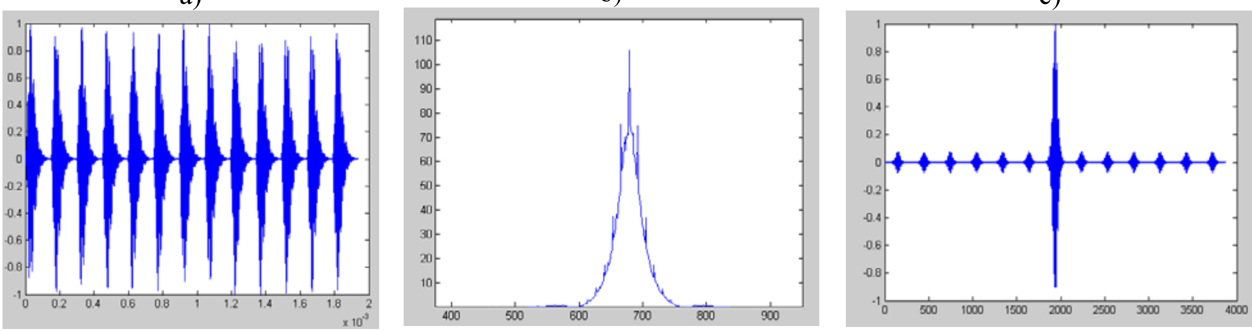

Fig.7 Transmitted signal (a), transmitted signal in frequency domain (90 kHz) (b) and autocorrelation of transmitted signal for Barker code (c)

a) b) c)

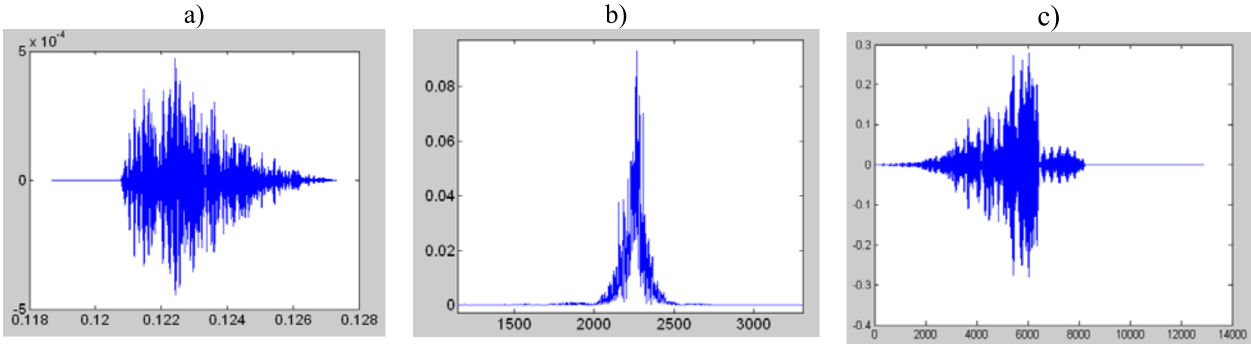

Fig.8 Backscattered signal (a), backscattered signal in frequency domain (80 kHz) (b) and cross correlation of echo with transmitted signal for Barker code (c)

In Fig 9 and Fig. 10, pulse shape, bandwidth and autocorrelation for signal and echo for longer, Gold code was used (31 chips, over two times longer than Barker code). As it may be seen from Fig. 10c, the peak value of the correlation function may be localized better than in previous case. More over the echo can be identified from the pseudo random sequence, as well.

5. CONCLUSIONS

Despite the latest achievements in broadband transducers, the bandwidth is still the main limitation. This is the reason that long transmitted signals used in the experiment still does not allow a bottom detection for very shallow water areas. Barker code was tested for length 4 and 5 and different Gold codes were tested with similar results as well.

The main advantages of the presented approach are: transmitted power decrease, better range detection resolution, and a signal pulse identification possibility. The advantages can be very useful for a bathymetry profiling for deep waters. The main disadvantages of the method is a complex and exacting receiver, however. It is worth to say that a correlator, the main part of the receiver could be implemented in the hardware. Such implementation is realized usually for high frequency operations [5]. The presented method is a kind of synchronized detection. Due to a relatively low level, the noise was neglected in the experiment, that is confirmed by other experiments [5].

a) b) c)

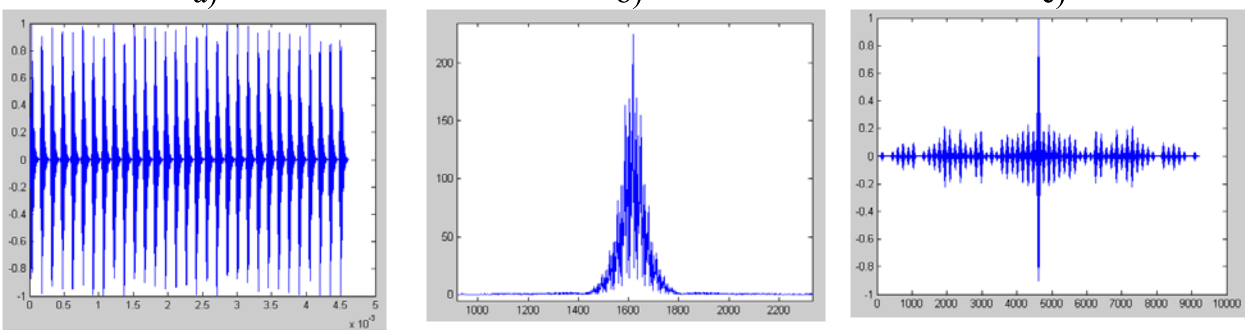

Fig.9 Transmitted signal (a), transmitted signal in frequency domain (90 kHz) (b) and autocorrelation of echo with transmitted signal for Gold code (c)

a) b) c)

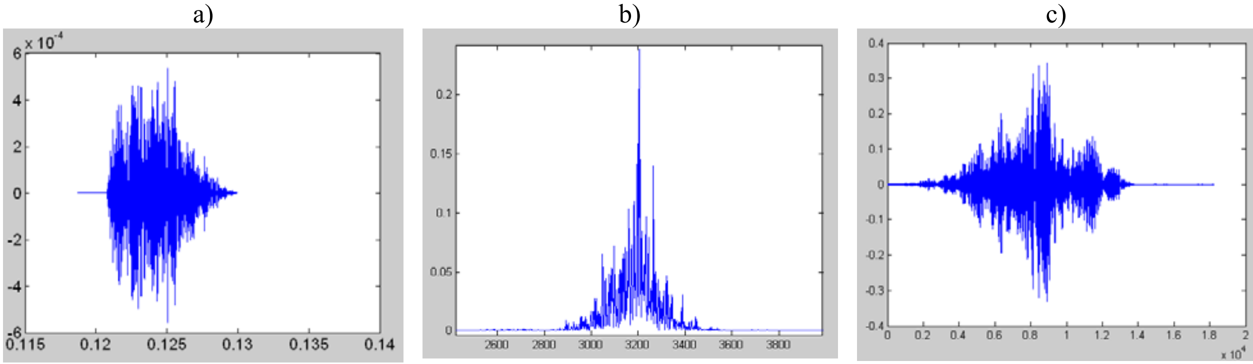

Fig.10 Backscattered signal (a), backscattered signal in frequency domain (80 kHz) (b) and cross correlation of echo with transmitted signal for Gold code (c)

It is possible that similarly to chirp like signals some subbottom profiling results may be valuable. The experiment does not cover the whole area of investigations, but it can be treated as a proposition to be carried out also with a slight modification of the method, the so called multicarrier spread spectrum developed in some extends by authors.

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