UDC 621.384.852

INCREASE OF INFORMATIVE CAPACITY OF ULTRA WIDE BAND IMPULSE SIGNALS

Sergii G. Bunin

National Technical University of Ukraine “KPI”, Kyiv, Ukraine

It is common to think that impulse radio ultra band signals (IR-UWB) in communication systems can carry the information at very high rates. But each impulse of the signal can carry just one bit of information. In radio networks it is necessary to add destination address to every information unit. The best way for each subscriber is use series of impulses mutually orthogonal to the rest of series in the network. But the orthogonality means long multi impulse series with low density of impulses to make time domain space transparent. As a result, data transmission rates become much less than expected. To increase data rates in radio networks modulation of each impulse by amplitude, duration and polarity in the series is proposed. Examples of transmitter and receiver are presented. As a result, informative loading on signals increases manifold, compensating or neutralizing losses, related to the transmission of symbols by impulse sequences.

Introduction

Efficiency of communication system is determined by the type of modulation and method of reception. Modulation characterizes the amount of information bits, transferrable during one increment of signal parameters change, and a method of reception is efficiency of detection (recognitions) of signal on a background noises and interference. This applies to the ultra wide band impulse signals radio systems (IR – UWB). The IR–UWB signals attract researcher’s attention thanks to the row of advantages over signals based on sine wave carriers [1].

The generation of impulse signals in principle does not represent difficulties. A problem consists of only availability of devices, able to generate the impulses of the required small duration and amplitude. The direct current impulse (fig.1a), given in an antenna, transforms into bipolar electromagnetic oscillation. If frequency and phase characteristic of the antenna is linear in the wide enough frequency band, then a form of the radiated electromagnetic impulse is the Gauss monocycle (fig.1b). The Gauss monocycle is bipolar oscillation – result of DC impulse differentiation by antenna. On a receiving side receiving antenna also differentiates the Gauss monocycle, as a result, a monocycle transforms into oscillation, the form of which is represented on fig.1c. If the antenna or propagation medium frequency bands look like a low-pass filters, then a monocycle transforms into a radio impulse with many oscillations and its duration becomes inversely proportional to the overall frequency pass band.

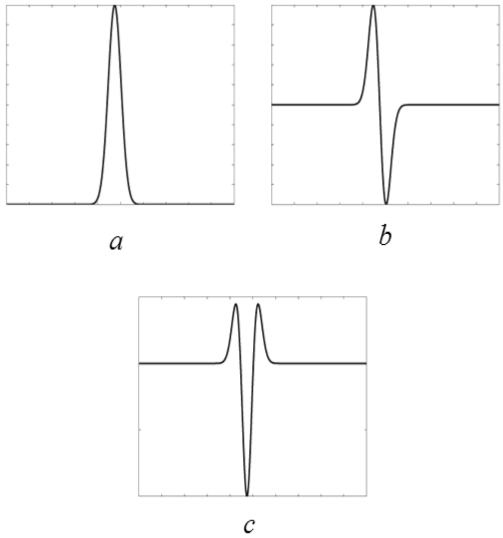


Fig. 1. Gauss impulse transformation in the process of transmission: *a* – DC Gauss impulse, *b* – first derivation of Gauss impulse, *c* – second derivation of Gauss impulse.

Task Setting

In a “point to point” communication, without interference from other impulse sources, each impulse represents only one bit of information. In radio networks with many impulses from and to different subscribers it is necessary to mark the impulses destinations, i.e. implement addresses of recipients. Mutual pair-wise synchronization of transmitters and receivers of the link can be used for this purpose allowing defining what impulses from whole streams of impulses in the network destinated to particular receiver. However, taking into account extraordinarily small durations of impulses (usually less than 10^{-9} sec), requirement to accuracy of synchronization must be the same order. It is also necessary to take into account that the reception of asynchronous in time informative blocks (packets, for example) requires preliminary search the synchronization before reception for every block, that, taking into account duration of impulses, does the search of synchronic signal very protracted, and packet communication not effective. Therefore, as the asynchronous data blocks transmission, it is necessary to apply an address “painting” on impulse signals, which would differentiate receivers without preliminary synchronization.

The most effective method of asynchronous transmission is usage of pulse-code modulation (PCM), at which information unit passes from a source to a recipient by certain impulse series orthogonal or quasiorthogonal to ones sending by other users. On a receiving side sequences distinguish by means of, for example, passive matched filters, which decode the impulse streams without synchronization (for example, based on a delay line with taps). It is clear, that the more impulses used for one information unit, the higher probability of their correct address decoding. However, the transmission of information units by sequences of impulses reduces transmission rates, both between the separate pairs of subscribers and in the whole network because chosen sequences must have relatively large average duty cycles (ratio of pauses between impulses to impulses duration) for possibility to create sufficient ensemble of sequences with impulses distinct in time. At the classic methods of reception, based on the accumulation of signal energy, the impulses of the spaced out sequences must have sufficient energy, which gives sufficient exceeding above the spectral noise density in the receiver. Unfortunately spaced out series of ultra short impulses cannot carry enough energy to fulfill the needed energy to noise spectrum density ratio. Therefore it is necessary to increase information capacity of code sequences to improve information rates in radio networks with IR-UWB signals. A way for this is usage of impulses modulation.

Modulation of Impulses

The Gauss monocycle has three independent parameters – amplitude, polarity, and duration. Polarity of the DC impulse changes initial phase of second derivation at front end of the receiver. By changing each of these parameters individually or jointly it is possible to “fill up” additional information to impulse sequences, i.e. to make for every impulse a construction in “amplitude-initial phase – duration” domain (Fig. 2), providing considerably larger information loading on every impulse and whole code sequence.

The vector of impulse can be placed in different positions, but in one of two half planes (phase 0 or 180 degrees). Signal constellation, determined by position of end of signal vector, can consist of great number of values in these half planes. Thus, the information "loading" will be similar to *M*-fold phase-amplitude modulation (PAM). Each impulse can carry $M=log_2\ k$ bits, where $k = 2^{ADP}$ – two to the number of product of gradation values of amplitude, phase, duration parameters. The whole address *L*- impulse sequence can carry $M{\cdot}L$ bits of information.

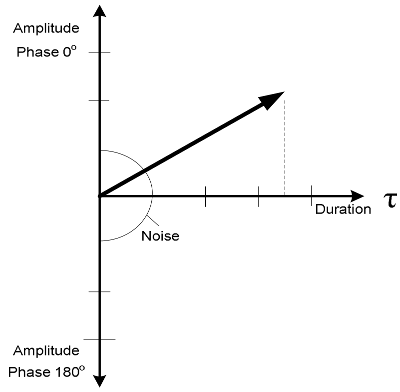


Fig. 2. Vector of impulse in “amplitude – phase – duration” domain.

It looks like there is no problem to distinguish impulse amplitudes in a receiver. There can be some problems to identify exact values of impulse duration, if there are some frequency limitations in pass band of antennas, propagation medium and in the receiver itself because of, mentioned higher, transformations of very short three half wave second derivation impulse into many half waves radio impulse. This means, that impulse duration gradation must exceed possible extension.

The most difficult process is to distinguish the initial polarity of impulse. Usually coherent correlation technique with strict synchronization is used to identify a phase of the impulse. But it looks possible to detect the polarity by non-coherent method by analyzing phases of the second derivation.

Let’s consider possible devices for transmission and reception of with amplitude, phase and duration modulated impulses.

Transmitter

A scheme of transmitter (fig. 3) consists of a bi-phase output stage, loaded on ultra wide band antenna. This stage is excited by a stage forming positive or negative polarity impulses (PDC); its duration set depends on the value of *M*-fold code word of input data stream coming from a coder. The address impulse sequence goes on address input of the coder. In the simplest case (without additional modulation) the address sequence can represent information units. Information data stream goes to the coder data input. The coder divides this stream into groups of bits, matches these groups with the impulse parameters in the code table and generates appropriate output control signals. Power control blocks (PCB) controls amplitude of the impulse. Thus, every address code sequence impulse additionally modulated by three parameters – amplitude, phase and duration.

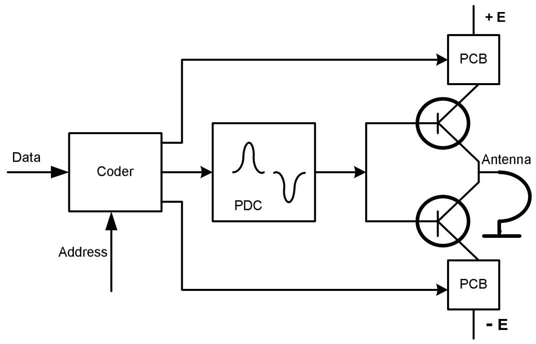


Fig. 3. Transmitter functional diagram.

Receiver

The noise immunity of such transmission system will be similar to the one of the systems with amplitude-phase modulation. Probability of error on receiving side will be determined by distances between the ends of impulse signal vectors and level of noise in the communication channel. Therefore, it is possible to offer such combinations of those three parameters, which would maximize distances for the similar groups of symbols (code words). Such a method (for instance, Gray codes) is used in the systems with amplitude-phase modulation [3].

Reception method also influences probability of error. In the “non-energy” reception method [3,4], which uses impulses with amplitudes higher than *rms* level of noise rather than impulses energy, error probability will be determined only by ability of receiver to distinguish gradation of each three parameters of the received impulses under given noise level. The signal processing is carried out by the use of “standard” impulses of selected amplitude and duration, generated in a receiver in reply to received ultra-short impulses. Correlation analyses of “standard” impulses streams by a matched filter without transmitter and receiver synchronization is the base of the method. Such method of reception substantially simplifies requirements to hardware-software facilities of a receiver.

Let us examine the possible diagram of an IR – UWB receiver with modulated impulses (fig.4). Forms of signals at some points of the diagram are shown on fig.5.

A signal from antenna amplified by the low noise amplifier LNA (point *a*) goes to two chains of quadrators (rectifiers). Output of quadrators is the half-wave video signals with opposite phases. They enter integrating and differentiate chains. The first ones average levels of signal and noise, second – selects ultra-short impulses of the signal and noise. Differential amplifiers compare levels from each of chains and selects impulses whose level exceeds the averaged value of noise. Amplitude limiter converts selected impulses into different phases rectangular forms (*d* and *e*). Rectangular impulses are summed up, integrated (*f*) and goes on to a decision device (bilateral threshold device). The impulse exceeding positive or negative threshold appears on the decision device output and indicates the phase of the received signal (*g*). Duration of this rectangular impulse is proportional to duration of the received one.

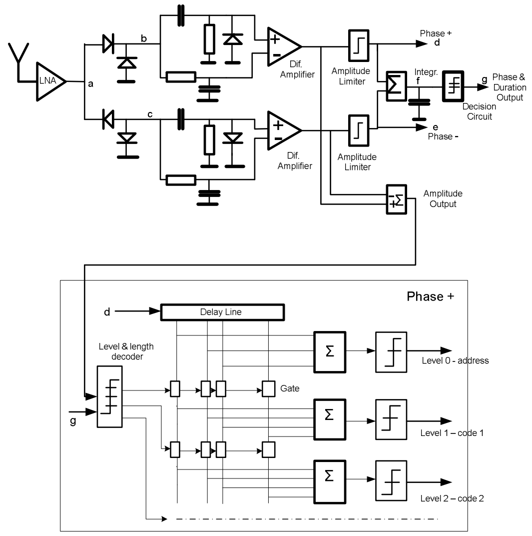
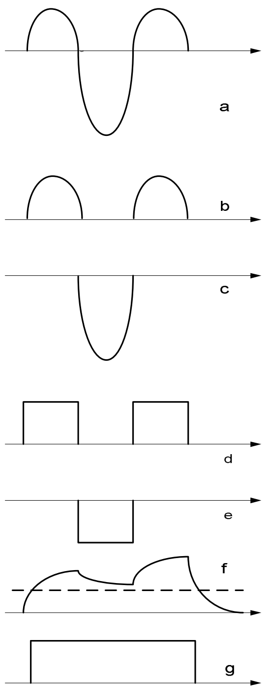


Fig. 4. Functional diagram of receiver.

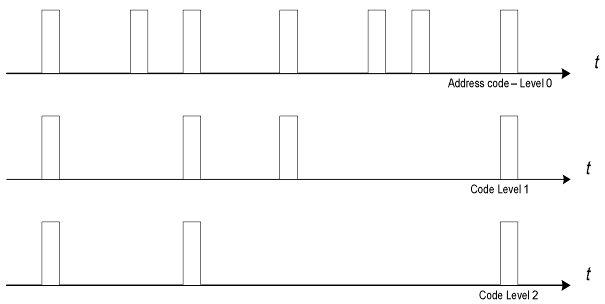
The lower part of the diagram illustrates the process of address decoding (decoding of the orthogonal impulse series with positive and negative impulse phase) and level selection of each of the impulses. Only positive initial phase process is shown on the diagram.

Basis of this part of the diagram is *A*-fold threshold device (*A* is the impulse amplitude level gradations) and delay line with taps and summator making matched filter. Impulses with positive phase go from *d* point. Summator Σ accumulates impulses from taps of the delay line and enter them on a decision threshold device. Exceeding the threshold indicates reception of address with positive impulse polarity sequence.

Simultaneously every impulse enters on *A*-fold threshold device, giving out signals on each of his outputs at exceeding of corresponding thresholds. These signals open keys (gates), allowing signals from taking of delay line to the next level summators with threshold devices. On the output of decision devices we get pulse series with levels, exceeding the address level by the corresponding amount of gradations. Fragments of address sequences are shown on fig.5*b*.



(*a*)



(*b*)

Fig.5. Signals curves at different points of the receiver: *a* – at different points of the receiver, *b* – output series of different levels.

An analogical presentation is used to illustrate possible ways of impulsive sequence decoding. Naturally, our day's digital methods and ASICs must be realized whenever possible.

All outputs of the receiver are connected to final decoder (not shown), which provides interpretation of received signals from all outputs into corresponding information and delivers the flow of data to the final receiver output.

Conclusion

In many works dedicated to application of IR – UWB signals in communication systems, possibility of very high rates of information transfer is firmly declared. This opinion bases on the Shannon theory, showing, that information transmission rates are proportional to the frequency spectrum, occupied by a signal. Really, the spectrum of ultra-short impulses is very wide, but each impulse can carry only one bit of information.

In radio networks the transmission of information requires addressing. It is more useful to carry out addressing by the transmission of informative units as mutually orthogonal code impulse sequences. For the increase of degree of mutual orthogonality it is needed to increase the amount of impulses combinations in sequences and diminish impulses duration. The increase of amount of impulses in address sequences at maintenance of sufficient size of average duty cycle results in lengthening of sequences and decline transmission rate. Diminishing of duration of impulses diminishes their energy that at the classic method of reception results in the decline signal energy to noise spectral density.

It is suggested to use the method of "non-power" reception of ultra-short impulse sequences, providing the signal processing without the account of energy, i.e. areas of the accepted impulses. Instead only their amplitudes exceeding noise level control, generation of receiver internal "standard" impulses, which are further used in signal processing. Besides, this method allows receiving asynchronous signals providing their correlation in passive matched filters.

The increase of informative capacity of impulse signals it is proposed to make simultaneous or separate modulation impulse's independent parameters of – amplitude, duration and polarity. A receiver must be able to distinguish the gradations of changes. Functional diagrams of possible transmitter and receiver are proposed.

Due to modulation of impulses the informative loading on signals increases manifold, compensating or neutralizing losses, related to the transmission of symbols by impulse sequences.

References

1. Miller L.E. Why UWB? A Review of Ultrawideband Technology // Report to NETEX Project Office, DARPA. Wireless Communications Technologies Group, National Institute of Standards and Technology, Gaithersburg, Maryland. – 2003. – No. 4. – 590 p.

2. Ghavami, L. B. Michael, R. Kohno – Signals and Systems in Communication Engineering. – John Wiley & Sons, Ltd.

3. S. Bunin, D.O. Dolzhenko Method of ultrashort impulse radio signals reception and the source device. Patent of Ukraine № 97705.

4. S. Bunin "Non-power" reception of ultra-short impulse radio signals // Telecommunication Sciences, No. 1, 2010. – 7 – 13.

Received in final form March 9, 2013