Investigation of Noise Immunity of Ultrawideband Pulse Radar Sensors on the Base of Single Chip

Andrey B. Borzov
Department of autonomous information and control systems, Bauman Moscow State Technical University, Moscow, Russia
borzov@bmstu.ru

Konstantin P. Likhoedenko
Department of autonomous information and control systems, Bauman Moscow State Technical University, Moscow, Russia
klikhoedenko@bmstu.ru

Grigory M. Seregin
Department of autonomous information and control systems, Bauman Moscow State Technical University, Moscow, Russia
seregin@bmstu.ru

Victor B. Suchkov*
Department of autonomous information and control systems, Bauman Moscow State Technical University, Moscow, Russia
vbs-2014@bmstu.ru

ABSTRACT

The principles of evaluating the noise immunity of ultrawideband pulse radars based on single-chip XeThru-Novelda transceivers are considered. A mathematical description of the method for reconstructing the signal shape from its mixture with jamming is given based on the analysis of the gated sampling algorithm in the XeThru-Novelda microcircuit. Functional diagram of a single-chip transceiver as part of the UWB pulse radar sensor and the scheme of the threshold level quantizer were developed. The result of reconstructing the pulse signal from its mixture with harmonic interference for different number of accumulated pulses is shown. The efficiency of the algorithm for synchronous accumulation of a large number of ultrashort pulses under the influence of a jamming signal to increase the signal-to-noise ratio is shown.

CCS CONCEPTS

• Hardware; **• Communication hardware, interfaces and storage**; **• Sensor applications and deployments**;

KEYWORDS

Ultrawideband, Pulse radar sensor, Noise immunity, Signal restoration, Jamming, Signal-noise ratio, Accumulation

ACM Reference Format:

Andrey B. Borzov, Konstantin P. Likhoedenko, Grigory M. Seregin, and Victor B. Suchkov*. 2021. Investigation of Noise Immunity of Ultrawideband Pulse Radar Sensors on the Base of Single Chip. In *The 5th International Conference on Computer Science and Application Engineering (CSAE 2021), October 19–21, 2021, Sanya, China.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3487075.3487105

CSAE 2021, October 19–21, 2021, Sanya, China

ACM ISBN 978-1-4503-8985-3/21/10…$15.00
https://doi.org/10.1145/3487075.3487105

1 INTRODUCTION

Nowadays, the most promising option for constructing of portable radar sensors with high range resolution is the use of a sequence of ultrashort pulses [1-9]. Ultra-short-pulse radar sensors can be used for through-wall radar systems for detecting moving objects, systems for determining the thickness of ice (snow), on-board high-resolution radar sensors, security systems, etc.

The receiver of the short pulse radar sensor can be developed on the basis of a comparator with a tunable threshold and an array of delay lines such as single-chip transceiver from XeThru-Novelda (Norway) [10-11]. With this version of the receiver construction, the power consumption of the device is almost an order of magnitude less than other known solutions [12]. Therefore, a single-chip transceiver from XeThru-Novelda can be chosen as a basic solution when developing a structural diagram of radar sensor [12].

The single-chip transceiver NVA6100 [10] with dimensions of 5×5 mm is a fully integrated ultra-short-pulse radar transceiver for low-power high-performance systems. It's a reliable solution for a wide range of remote sensing applications in portable short-range radar systems. The single-chip NVA6100 transceiver operates in the 1-4 GHz wide band and generates ultrashort pulses with a Gaussian 1st derivative waveform and a duration of 0.6 ns.

Due to the fact that in a single-chip transceiver, the generator of radiated pulses and the receiving circuit are combined in one module, the structural diagram of the ultrawideband (UWB) pulse radar transceiver should contain single radar chip, low noise amplifier, band-pass filter for rejection of noises outside the working band, power amplifier, secondary power supply (Figure 1).

In terms of power consumption, the power consumed by the entire transceiver module on a single-chip transceiver (Figure 1) is no more than 1 W, and the overall dimensions of such a transceiver module on a single-chip integrated circuit do not exceed 52 mm [12]. One of the problems for real applications of UWB pulse radar systems is their noise immunity in conditions of acting some kind of jamming. There are some interesting applications of UWB pulse radar on the base of XeThru-Novelda microcircuit [5-9] but the problems of jamming's rejection in such systems weren't be discussed in details.

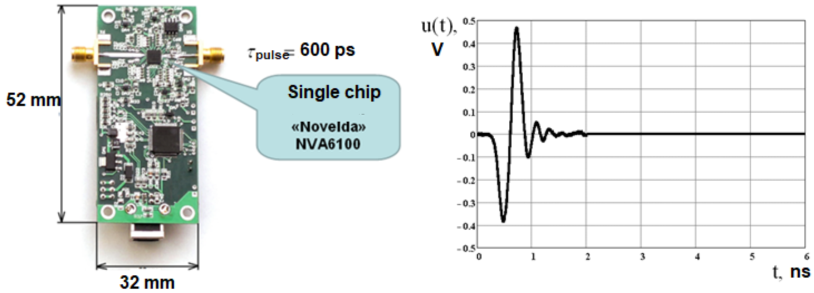

Figure 1: Transceiver Module of UWB Short-Range Radar System Based on a Single-Chip NVA 6100 (Duration of the Generated Pulse 600 ps).

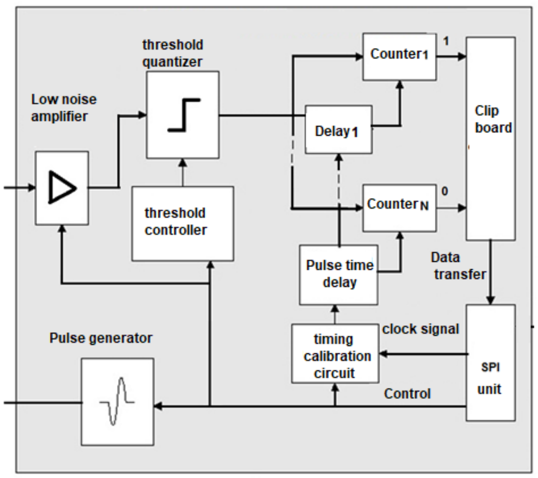

Figure 2: Functional Diagram of a Single-Chip Transceiver as Part of the UWB Pulse Radar Sensor.

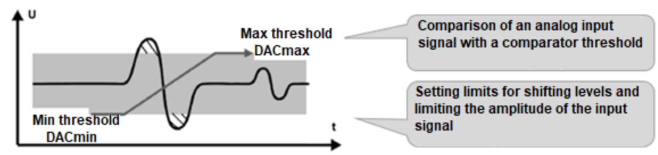

Figure 3: The Scheme of the Threshold Level Quantizer.

2 THEORETICAL BACKGROUND

As a parameter of noise immunity, the UWB radar sensor can set the signal-to-noise ratio (SNR) of the receiving device, which is defined as the ratio of the peak power of the ultrashort pulse received by the receiving device to the dispersion of the noise signal power:

$$q_{SN} = \frac{P_{max}}{\sigma_N^2}, \tag{1}$$

Where P_{max} - peak power of pulse signal, W; σ_N^2 - dispersion of the jamming signal, W.

It is necessary to consider the functional diagram of a single-chip transceiver, consider the main functional blocks, principles of their operation and signal processing algorithms after restoring its shape [13]. Figure 2 shows the functional diagram of the NVA6100 single-chip transceiver as part of the structural diagram of the UWB pulse radar sensor.

The NVA6100 microcircuit implements a gated sampling algorithm for the input signal. The presence of high-frequency components in the frequency spectrum of UWB pulse signals causes high requirements for the receiver. Converting microwave signals at frequencies of several GHz into digital form requires extremely fast analog-to-digital converters (ADCs). Gated sampling radar systems must use high precision time delays and high speed sampling. The gated sampler used in the NVA6100 operates in a continuous time domain, without using a clock to take digital samples. The signal is converted from analog to digital and achieved picosecond accuracy in measuring the signal propagation time without using high-frequency clock signals.

The transceiver of NVA6100 uses a comparison of the analog input signal with a comparator threshold. The received analog signal from the output of the receiving antenna is fed to the input contact of the NVA6100 microcircuit and then amplified in a low-noise amplifier, which has 7 gain levels and a gain range from -6 dB to 23 dB. The signal is then fed to the input of a high-speed threshold quantizer. A quantizer comparator compares the input signal with a threshold voltage and decides whether the signal level is below or above this threshold level. A digital signal is formed at the output of the quantizer, which will be continuous in time.

The threshold quantizer is controlled by a 13-bit threshold controller, which allows you to generate a maximum of 8192 threshold levels and control the level shift. The voltage threshold used in quantization is generated in the built-in digital-to-analog converter (DAC). The threshold is shifted over the range of voltage values of interest, adjustable by the step of setting the threshold, to achieve the desired result. The two most important inputs to the threshold controller are DACmin (minimum DAC threshold) and DACmax (maximum DAC threshold). They set boundaries for the level shift and limit the possible amplitude range of the input signal. Figure 3 shows a diagram for setting these parameters.

After conversion the signal into a binary sequence with use of a threshold quantizer the array of parallel samplers will be filled. This array contains 512 samplers. The sampler is gated using the time delay of the frame. The signal from the comparator output is fed to parallel samplers, each with a certain sampling interval. Controlled range interval, i.e. the region of space from which the transceiver receives the reflected signal is directly proportional to the sampling interval.

The signal reconstruction algorithm in NVA6100 [10-11] allows reconstruction of the analog single pulse shape in digital form with high accuracy in the time domain. For a rough reconstruction in the amplitude region, at least 4-8 received pulses are required, for accurate recovery up to 8192 pulses. The NVA6100 sampling scheme has one comparator in the threshold quantizer and 512 digital counters, which are written binary values with a minimum sampling interval of 26 ps. After comparing with the predetermined threshold level and sampling the signal, the threshold level controller sets a new threshold value, and the sampling procedure continues until the threshold value is shifted along the amplitude region.

For each step of the threshold shift, the result of signal conversion to digital form is accumulated in a digital counter. In the absence of noise in the surrounding space, the amplitude resolution of the system is set by the value of the threshold change. After the change in the threshold level is completed, i.e. the comparison with all preset threshold levels has taken place, the digital value of the signal can be selected from the counter. Significant averaging may be required to recover a noisy signal. The NVA6100 transceiver uses digital counters as a digital averaging circuit. The NVA6100 uses 32-bit digital counters and can accumulate and average tens and hundreds of pulses.

3 ALGORITHM OF NOISE IMMUNITY ESTIMATION

3.1 Technique of Pulse Signal Restoration

On the basis of the considered features of the operation of a single-chip transceiver for reconstructing the shape of the UWB pulse signal, it is possible to obtain the basic relations of the algorithm for receiving the input UWB pulse signal. This algorithm is based on the principle of synchronous accumulation of a large number of ultrashort pulses coming from the UWB antenna output:

$$s_u(t) = U_{inp}(t), \qquad 0 \le t \le T, \tag{2}$$

where $U_{inp}(t)$ - voltage of the received pulse signal by UWB antenna, V; T - pulse repetition period, s; $u = 0..N_{puls} - 1$ - index of the received pulse signal.

At the first step, the expected range of input signal amplitudes $\{s_{min}..s_{max}\}$ is set, which correspond to the DACmin (minimum DAC threshold value) and DACmax (maximum DAC threshold value) in the NVA6100 microcircuit. They set the boundaries for the level shift and limit the possible amplitude range of the input pulse signal. The range of values can be selected as a result of mathematical modeling of signals reflected from typical targets at the required detection ranges of the UWB pulse radar sensor.

At the second step of the algorithm, an array of signal threshold levels is formed, and the number of thresholds must be equal to the number of accumulated pulses. At the third step, a cycle is organized according to the number of received pulses. Each received pulse is divided in time into 512 samplers , each of which corresponds to the averaged signal level over a time sampling interval of 26 ps.

For a sampling interval of 26 ps and a number of samplers of 512, the time interval in which the waveform is restored is defined as $T_m = m \cdot \Delta t = 13,31$ ns. To implement the accumulation of impulses, an array of counters $M[k], 0 \le k \le m$ is formed, in which the values of the number of exceedances of the discrete values of the signal of the set threshold values will be stored. The index of each counter k corresponds to the sampler number. In the cycle, according to the number of received pulses $u = 0..N_{puls} - 1$, the array of counters for exceeding discrete values of the threshold signal for each received pulse is filled.

After the end of the accumulation of pulses, M [k] is the shape of the reconstructed pulse signal. For the convenience of analyzing and processing the recovered signal, it should be normalized to the maximum number of exceedances M_{max} of the threshold relative to the average value of the number $\bar{M}$ of exceedances for the entire accumulation time.

The general scheme of the algorithm for reconstructing the pulse signal in the receiver of the radar sensor, which implements the principle of synchronous accumulation of is shown in Figure 4.

The scheme dividing the received pulse into discretizers is shown in Figure 5. Figure 5 shows the process of reconstructing the shape of the received pulse according to the considered algorithm using the example of pulse signal with a duration of 600 ps with a repetition period T = 100 ns (signal from the output of the NVA6100 transceiver). As the range of amplitudes of the input signal $\{s_{min}..s_{max}\}$, its minimum and maximum values are taken, respectively $s_{min} = -0,38\ V,\ s_{max} = 0.45V$.

3.2 Technique of Noise Immunity Estimation

To estimate the effectiveness of the developed reception algorithm under the influence of a jamming, it would be possible to consider the process of reconstructing UWB pulse signal in an additive mixture with jammimg. As a jamming signal, we will consider a harmonic jamming from the output of the receiving antenna. We represent the mathematical model of the jamming as a continuous harmonic signal:

$$n(t) = U_n \cdot \cos(2\pi f_0 t), \tag{3}$$

where U_n - is the amplitude of the harmonic noise voltage, V; f_0 - frequency of harmonic jamming, Hz.

Then, as the signal intended for restoration, we will consider the additive mixture of the UWB pulse signal shown in Figure 1, and an jamming signal of the form (3):

$$s_u^{SN} = s_u(t) + n(t), \tag{4}$$

To estimate the efficiency of recovering the UWB pulse signal from its additive mixture with jamming, we will use the SNR estimate (1) in relation to the normalized values of the amplitude of the reconstructed signal:

$$q_{SN} = \frac{\tilde{P}_{max}}{\tilde{\sigma}_N^2} \tag{5}$$

where $\tilde{P}_{max}$ - normalized peak power of the recovered signal; $\tilde{\sigma}_N^2$ - normalized dispersion of the power of the reconstructed jamming.

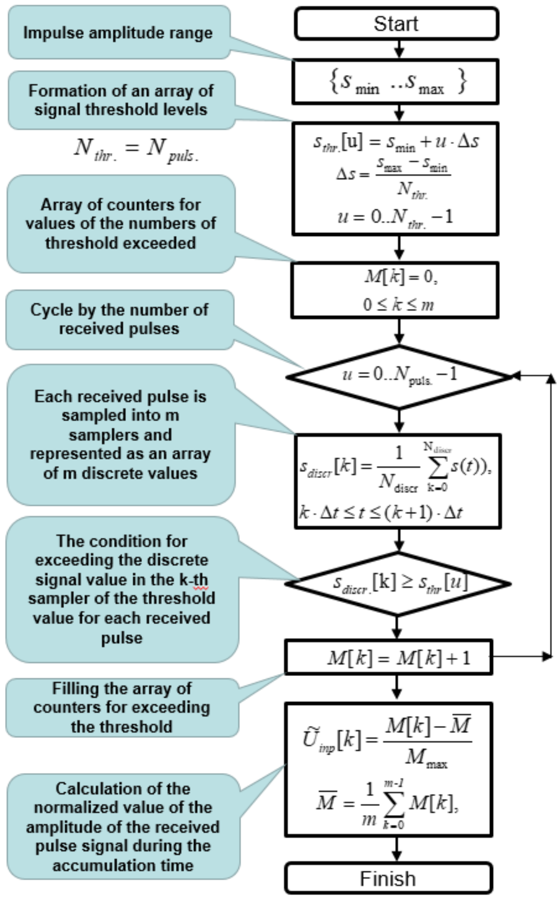

Figure 4: Block Diagram of the Algorithm for Recovering the Received UWB Pulse Signal by a Single-Chip Transceiver.

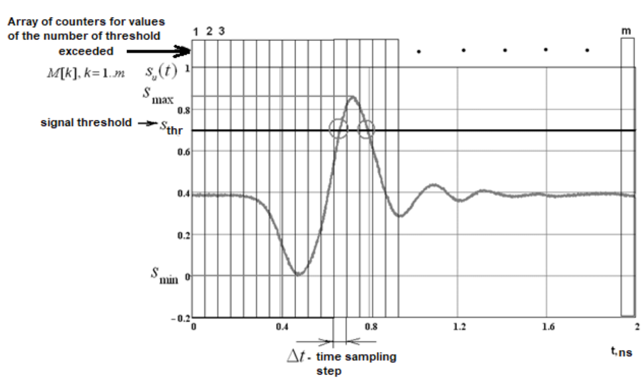

Figure 5: Sampling Scheme of the Received Pulse Signal.

As the normalized peak power of the reconstructed signal, we will consider the square of the maximum value of the amplitude of the reconstructed pulse signal from its mixture with interference:

$$\tilde{P}_{max} = max^2 \left\{ \tilde{U}_{inp.}^{SN} [k] \right\}, \tag{6}$$

where $\tilde{U}_{inp.}^{SN} [k]$ - normalized value of the amplitude of the received signal in a mixture with interference during the accumulation time.

As a normalized value of the variance of the power of the reconstructed interference signal, we take its estimate provided that only the jamming signal (3) is reconstructed according to the given algorithm during the same accumulation time and in the same threshold range as the useful UWB pulse signal:

$$\tilde{\sigma}_N^2 = \left(\frac{1}{m} \cdot \sum_{k=0}^{m} \left(\tilde{U}_{inp.}^{N} [k] \right)^2 \right) - \left(\frac{1}{m} \cdot \sum_{k=0}^{m} \tilde{U}_{inp.}^{N} [k] \right)^2, \tag{7}$$

where $\tilde{U}_{inp.}^{N} [k]$ - the normalized value of the amplitude of the received jamming signal during the accumulation time.

Then, in accordance with (3)-(7), we obtain the final expression for estimating the signal-to-noise ratio (SNR) of a transceiver that implements the algorithm for synchronous accumulation of a large number of pulses:

$$q_{SN} = \frac{max^2 \left\{ \tilde{U}_{inp.}^{SN} [k] \right\}}{\left(\frac{1}{m} \cdot \sum_{k=0}^{m} \left(\tilde{U}_{inp.}^{N} [k] \right)^2 \right) - \left(\frac{1}{m} \cdot \sum_{k=0}^{m} \tilde{U}_{inp.}^{N} [k] \right)^2}, \tag{8}$$

To investigate the noise immunity of pulse radar sensors on the base of synchronous accumulation of a large number of pulses it is necessary to estimate dependence of the SNR on the number of accumulated pulses.

4 ANALYSIS OF RESULTS OF DIGITAL SIMULATION

Due to the fact that the pulse signal with a duration of 600 ps (Figure 1) has a frequency band from 1 to 4 GHz we will choose f_0=1.1 GHz as a frequency of the harmonic jamming. To estimate the efficiency of the recovery algorithm, we will consider that the amplitude of the jamming is greater than the amplitude of the useful pulse signal $\frac{U_N}{U_S} = 4$. The recovery of the pulse signal from its additive mixture with noise (3) was carried out with the accumulation of a different number of pulses: N_{puls}=5000 and 10000 (Figure 6).

So for the case when the amplitude of the jamming is greater than the amplitude of the signal, the accumulation of 5000 pulses leads to distortion of the shape of the reconstructed pulse (Figure 6), and therefore at least 10000 pulses are required for effective reconstruction of the pulse shape.

In accordance with (8), the dependences of the SNR (Figure 7) on the number of accumulated pulses were calculated when the pulse signal with a duration of 600 ps was reconstructed from its additive mixture with harmonic noise at various ratios of the amplitudes of the noise and the signal U_N/U_S.

For all values U_N/U_S and for the number of accumulated pulses N_{puls}>1000, the SNR values $q_{SN} \geq 5$ dB of the reconstructed pulse signal are provided, even when the amplitude of the jamming is greater than the amplitude of the signal. To provide SNR $q_{SN} \geq 10$ dB at the values $U_N/U_S \geq 1$ at least 2000 accumulated pulses

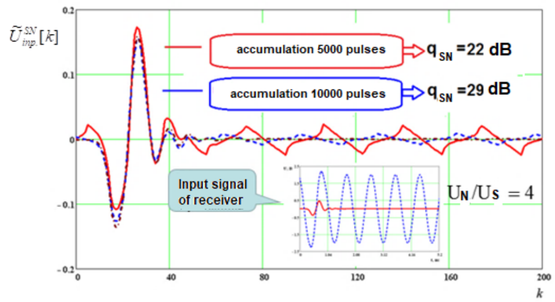

Figure 6: The Result of Reconstructing the Pulse Signal from Its Mixture with Harmonic Interference (Solid Line - 5000 Pulses, Dashed Line - 10000 Pulses).

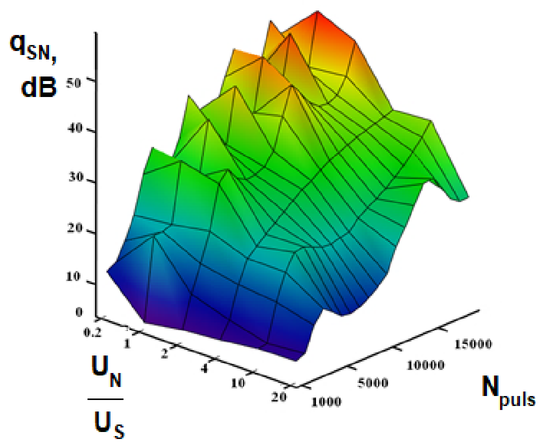

Figure 7: The Result of Digital Simulation of SNR in Dependence on the Number of Accumulated Pulses and on the Value of the Ratio of the Amplitudes of Jamming and Signal.

are required. Accordingly, with the number of accumulated pulses N=5000 and more, sufficiently high values of the SNR $q_{SN} = 20..40$ dB are provided in the all range U_N/U_S, which indicates a sufficiently high efficiency of the algorithm for receiving the UWB pulse signal. The efficiency of algorithm could be explained the opportunity of NVA6100 microcircuit to restore signal form by accumulation of a large number of pulses for short time.

5 CONCLUSIONS

In this article, the structure of an anti-jamming radar sensor on the base of single-chip microcircuit NVA6100 with low power consumption, small size, high resolution and high noise immunity has been developed. An algorithm has been developed for receiving a pulse signal in a radar sensor using synchronous accumulation of a large number of pulses based on a functional diagram of a single-chip transceiver. The implementation of the developed algorithm for receiving the pulse signal made it possible to obtain the dependence of the SNR on the number of accumulated pulses at different values U_N/U_S jamming and signal. The efficiency of the pulse signal reception algorithm justified on the basis of SNR values $q_{SN} = 5..45$ dB with the number of accumulated pulses N>1000, even when the jamming amplitude at the receiver input is greater than the signal amplitude. With use of the developed algorithm the number of thresholds (accumulating pulses) NVA6100 could be set for operating UWB pulse sensors in the influence of continuous jamming. It would be useful for efficient operating through wall UWB pulse radars and radar sensors for rejecting of jamming signals.

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