SIGNAL PROCESSING IN UWB RADARS OF SMALL DISTANCE

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Abstract
In the paper, the methods of signal processing with reference to Ultra-Wide Band (UWB) radars designed for detection and remote measuring parameters of moving objects at short ranges (tens of centimeters - several meters) are considered. It is shown that the relative changes of an oscillation frequency filling an outgoing pulse and duration of these pulses originating at reflection from a moving target are very small; that makes impossible their practical measurement. Therefore, for detection of signals reflected from a moving target the phase method is chosen.

Keywords: Ultra-Wide Band, Radar, Processing, Phase Method, Strobe Pulse.

1. INTRODUCTION
The system for processing received signals, represented in the paper, was used in UWB radars of small radius of action designed for remote measuring the critical parameters of man's vital activity that is heartbeat and respiration rate.

In this UWB radar designed for detection of signals reflected from a moving target, the phase method was chosen, as the relative changes of an oscillation frequency filling an outgoing pulse and pulses duration originating at reflection from a moving target are very small; so their practical measurement is very difficultly.

2. THE DESCRIPTION OF THE PHASE METHOD
The method is based on the measurement of the phase difference between radiated oscillations of outgoing pulses and received reflected radio signals. The block diagram of the processing system is shown in Fig. 1.

![Block diagram of the processing system](image)

The UWB outgoing pulse with a center spectrum frequency \( f_0 \) is generated in the transmitter TX and radiated by the transmit antenna \( WA_{TX} \).

The instantaneous value of the oscillations phase of an outgoing pulse is determined as follows:

\[
\phi_1 = 2\pi f_0 t - \phi_0 \tag{1}
\]

Where \( f_0 \) is the center frequency of the outgoing pulse's spectrum; \( \phi_0 \) is the initial oscillation phase.

Let's assume that the target is moving back-and-forth by the sine-wave law (the task of detection of a motionless person by thorax movement). In this case, the instant phase of an outgoing pulse reflected by a target will be determined by the following equation:

\[
\phi_2(t) = \phi_1(t) - 2\pi f_0 \times \frac{c R_{\text{max}}}{V} \sin(2\pi F_c t + R_0) - \theta \tag{2}
\]

Where \( R_{\text{max}} \) is the maximum amplitude of target's mechanical oscillation; \( R_0 \) is the minimum distance from the antennas of the sensor unit to the target; \( V \) is the speed of outgoing pulse's propagation in space; \( F_c \) is the frequency of target's mechanical oscillation; \( \theta \) is the angle, which takes into account the phase change of the outgoing pulse at reflection.

The phase difference between direct and reflected signals can be determined by Equation (3).

\[
\phi_1(t) - \phi_2(t) = 2\pi f_0 \times \frac{c R_{\text{max}}}{V} \sin(2\pi F_c t + R_0) + \theta \tag{3}
\]

Thus, the phase difference between oscillations of direct and reflected signals is determined by the finite speed of radio wave propagation, depends on the distance to a reflecting object, and varies from one probing period to another owing to changes in a delay time.

The comparison between phases of reference signals generated in the transmitter TX and received reflected signals is performed by the mixer U1. The low-pass filter (LPF) Z2 fixes this phase difference in
each period of probe. The low-cut filter (LCF) Z1 is intended to remove a DC component caused by the angle \( \theta \) and reflections from motionless surrounding objects (passive interferences). Then, the detected signal is amplified by the low-frequency amplifier A1 and goes to the system output. The signal obtained thus is proportional to a phase difference between an outgoing pulse (reference signal) and a signal reflected from the moving target (3).

3. **Mathematical model of the system**

Let’s consider the operation of the system on the basis of mathematical model, in the case when as a reference signal we use a video pulse with Gaussian envelope. Such a choice of the reference signal’s waveform allows making a considered system with the minimum costs. Mathematically, such a signal is described as follows:

\[
s(t) = E_s \cdot e^{-\frac{t^2}{2\tau^2}}\]

(4)

Where \( E_s \) is the maximum amplitude of pulse gate; \( \tau \) is the gate pulse duration by a level 0.606 from the maximum amplitude value.

Let’s write down the mathematical equation describing operation of the system:

\[
W = \frac{1}{R} \int_{-\infty}^{\infty} u(t) \cdot s(t) dt
\]

(5)

Where \( u(t) \) is the received signal reflected from the target; \( s(t) \) is the reference signal generated in the transmitter, which is coherent to the outgoing pulse; \( R \) is the load resistance.

To reduce a DC component, which appears owing to the signal reflection from a motionless underlying surface, the reference signal phased with a radiated signal should be given at time moments, when the received signal is crossing a zero level. In this case, we get:

\[
W = \frac{E_0 E_s}{R} \int_{-\infty}^{\infty} \left[ e^{-\frac{t^2}{2\tau^2}} - e^{-\frac{t^2}{2\tau^2}} \sin \left( \frac{2\pi t}{T_s} \right) \right] dt = \frac{E_0 E_s}{R} \int_{-\infty}^{\infty} \left[ e^{-\frac{t^2}{2\tau^2}} \left[ \frac{t}{\tau \tau_s} \right] \right] \sin \left( \frac{2\pi t}{T_s} \right) dt = 0
\]

(6)

Where \( T_s \) is the period of oscillations filling the outgoing pulse; \( \tau \) is the duration of the received signal; \( \tau_s \) is the duration of the reference signal; \( E_0, E_s \) are the maximum amplitudes of the received and the reference signals correspondingly.

The dissipation power in the load LPF Z2 is equal to zero at any relationship between the duration of a gating pulse and the duration of a received signal. This is illustrated by Equation (6).

For an estimation of losses originating at processing, we change the phase of a received signal at 90°. In this case, the power of interaction between received signals and gate pulses (reference signals) at the system output (Fig. 1) will be defined by the following equation:

\[
W = \frac{1}{R} \int_{-\infty}^{\infty} u(t) \cdot s(t) dt = \frac{E_0 E_s}{R} \int_{-\infty}^{\infty} \left( e^{-\frac{t^2}{2\tau^2}} - e^{-\frac{t^2}{2\tau^2}} \cos \left( \frac{2\pi t}{T_s} \right) \right) dt = \frac{E_0 E_s}{R} \int_{-\infty}^{\infty} \left[ e^{-\frac{t^2}{2\tau^2}} \left[ \frac{t}{\tau \tau_s} \right] \right] \cos \left( \frac{2\pi t}{T_s} \right) dt
\]

(7)

After the solution of the integral in Eq. (7) we get:

\[
W = \frac{E_0 E_s}{R} \frac{\tau \sqrt{2\pi}}{\sqrt{\pi^2 + \tau_s^2}} \cdot e^{-\left( \frac{(\pi \tau \tau_s)^2}{2(\pi \tau^2 \tau_s^2)} \right)} \quad (8)
\]

The dependence of this function on the duration of gate pulses is illustrated by the graph in Fig. 2.

**Fig. 2.** The graph of the dependence of a power dissipating at the processing system’s load on the gate pulse’s duration (\( \tau_s \)) at \( E_0 = 1; E_s = 1; \tau = 5.38; T_s = 2.5; R = 50 \)

On the graph, the function maximum is well allocated. Let’s define the optimal value of the duration of gate pulses, at which the dissipation power at a load has a maximum value. For this purpose, we differentiate the equation determined the power of an allocated signal (8) with respect to \( \tau_s \); having equated the obtained expression to zero, we find the optimum value of the reference signal’s duration.

\[
W' = \left[ \frac{E_0 E_s}{2R} \frac{\tau \sqrt{2\pi}}{\sqrt{\pi^2 + \tau_s^2}} \cdot e^{-\left( \frac{(\pi \tau \tau_s)^2}{2(\pi \tau^2 \tau_s^2)} \right)} \right]' =
\]

2 Ultra Wideband and Ultra Short Impulse Signals, 19-22 September, 2004, Sevastopol, Ukraine
\[ \tau \sqrt{2\pi} \frac{E_s E_r}{2R} \left[ (\pi \cdot \tau_s)^2 - (T_s^2)^2 \right] \times \exp \left[ -\frac{(\pi \cdot \tau_s)^2}{T_s^2} \right] = 0 \] (9)

The roots of the equation are determined by the following expression:

\[ \tau^*_{s, \tau^*} = \pm \frac{T_s}{\sqrt{(\omega_0 \tau)^2 - 4}} \] (10)

Where \( \tau \), the duration of the received signal; \( \omega_0 \) is the circular frequency of oscillations filling the outgoing pulses.

By analyzing Eq. (10), we came to the following conclusions: the optimum duration of gate pulses practically does not depend on the duration of a received signal but depends on the frequency (period) of oscillations filling a received signal. In addition, an increase in the duration of a received signal (at constant frequency of filling) results in proportional increase of power losses at the given type of processing.

Let's estimate a relative level of losses originating at processing. It is determined by the ratio of the power dissipating at a load of the processing system (8) to a total signal power.

\[ \gamma [dB] = 10 \log \left( \frac{W_{out}}{W_{total}} \right) = 10 \log \left[ 2 \sqrt{2} \frac{E_s \cdot \tau_s \cdot \exp \left[ -\frac{(\omega_0 \cdot \tau_s \cdot \tau)^2}{8(\tau_s^2 + \tau^2)} \right]} {E_r \sqrt{\tau_s^2 + \tau^2} \cdot \exp \left[ -\left( \frac{\omega_0 \tau}{2} \right)^2 \right] - 1} \right] \] (11)

The graph of the processing loss as a function of the gate pulse's duration is shown in Fig. 3.

For the case considered, the minimum value of losses (\( E_s = 1; \ E_r = 1; \ R = 50; \ \tau = 5.38; \ \omega_0 = 2.51 \)) is achieved with an optimum duration of a gate pulse, which is defined by Eq. (11) and is equal -5.95 dB.

4. CONCLUSION

- To remove passive interferences originating at detection of moving targets, it is necessary to sample such temporary provision of a gate pulse that the moment of feed of this pulse has coincided with the moment of cross of oscillations filling a received signal through a zero (maximum value of the derivative function of a signal). In this case, the DC component given by reflections of outgoing pulses from motionless objects and underlying terrain will not be generated at the system output.

- For reduction of losses originating at processing, the duration of video gate pulses of the Gaussian form should be determined under the equation (10).

REFERENCES