COHERENT DETECTION OF TWO-DIMENSIONAL DIGITAL MODULATION SIGNALS

Oryabinskaya O.A., Rozenvasser D.M.

O. S. Popov Odesa National Academy of Telecommunications,
1 Kuznechna St., Odessa, 65029, Ukraine.
oryabinskaya_onat@ukr.net; rozenvasser@onat.edu.ua

Abstract. Two-dimensional digital modulations require coherent detection to eliminate phase uncertainty. The main problem is that it is necessary to exactly match the frequencies and initial phases of the carrier and reference oscillations in the two processing channels and the phase difference in the subchannels at exactly \( \pi / 2 \). This article proposes a joint algorithm for clock recovery and phase adjustment of the reference oscillator of a two-dimensional digital modulation demodulator. If there is a delay in the beginning of the pulse, at the moment of transition from one channel symbol to another there will be a phase jump equal to the phase difference of the transmitted channel symbols. To determine the transition from one channel symbol to another, it is necessary to clearly define the moment of the jump. To do this, it is necessary to form a signal for the difference in phase values across the sampling interval. At the time of a phase jump, a single, substantially non-zero jump will be observed. The moment of the jump will determine the beginning of the channel symbol. The error of the start pulse adjustment will not exceed the sampling interval. Algorithm adjustment of the reference generator. The proposed algorithm is intended to use for determining the phase \( \phi_0 \) of the intermediate results of the clock recovery system. Sampling of values is performed within certain limits of the channel symbol and averaging is performed. Then it is necessary to introduce a correction of the phase value taking into account the clock adjustment. The proposed algorithm eliminates the mutual effects on the results of the estimates of the delay and phase adjustment. That is, the phase increment due to the delay in the channel does not affect the result of evaluating the phase increment due to the mismatch between the phases of the carrier and reference oscillations, despite the fact that the adjustment is made by phase error.

Key words: two-dimensional digital modulation, coherent detection, phase adjustment, clock recovery.

Coherent detection of two-dimensional digital modulation signals

Oryabinskaya O.A., Rozenvasser D.M.
The purpose of this article is to solve the problem of coherent detection by quadrature detection of two-dimensional digital modulation signals, whose coordinate channel symbols can acquire negative values. The main problem is that you need an exact match between the frequencies and the initial phases of the carrier and reference oscillations. This will be achieved only with the exact equality of the frequencies and initial phases of the reference oscillations with the frequencies and initial phases of the carrier oscillations in the two processing channels and the difference between their phases exactly on $\pi/2$. In fact, this ideal condition is unattainable. The currently existing quadrature detection method allows coherent detection under the condition of one-dimensional modulation and non-negative values of the modulating signal (MASK) [1]. MASK modulation has low noise immunity and therefore does not find widespread use in communication and broadcasting systems. The purpose of this article is to solve the problem of coherent detection by quadrature detector of digital modulation signals, whose coordinate channel symbols can acquire negative values.
Quadrature representation of the received two-dimensional signal $z(t)$. The signal at the output of the Gaussian channel will be mathematically described [2]:

$$z(t) = (a_c(t + \tau)A(t) + n_c(t))\cos(2\pi f_0(t + \tau) + \phi_0) + (a_s(t + \tau)A(t) + n_s(t))\sin(2\pi f_0(t + \tau) + \phi_0),$$  \hspace{1cm} (1)

where $a_c(t)$ and $a_s(t)$ – coordinates of channel symbols; $A(t)$ – envelope of channel symbols with a spectrum root of the Nyquist spectrum; $n_c(t)$ and $n_s(t)$ – quadrature components AWGN; $f_0$ – carrier frequency; $\tau$ – channel propagation delay; $\phi_0$ – phase increment in the channel.

As can be seen from Formula (1), to ensure coherent detection, it is necessary to take into account not only the phase increment in the channel, but also the phase increment due to propagation delay. Eliminating the phase increment due to the propagation delay is possible by ensuring accurate clock recovery.

Clock recovery algorithm. To ensure clock recovery, signals from the outputs of the quadrature splitter are proposed to be sampled at intervals $T_s << T$. Calculating the values of the phase on each subsequent clock cycle, it is necessary to subtract the phase increment corresponding to the delay. Thus, we obtain a series of phase values calculated by the following algorithm:

$$\psi_i(0) = \arcsin\left(\frac{\bar{a}_i(0)}{\sqrt{\bar{a}_i^2(0) + \bar{a}_i^2(0)}}\right),$$  \hspace{1cm} (2)

$$\psi_i(T_s) = \arcsin\left(\frac{\bar{a}_i(T_s)}{\sqrt{\bar{a}_i^2(T_s) + \bar{a}_i^2(T_s)}}\right) - 2\pi f_0 T_s,$$

$$\psi_i(2T_s) = \arcsin\left(\frac{\bar{a}_i(2T_s)}{\sqrt{\bar{a}_i^2(2T_s) + \bar{a}_i^2(2T_s)}}\right) - 2\pi f_0 2T_s,$$

$$\vdots$$

$$\psi_i(T) = \arcsin\left(\frac{\bar{a}_i(T)}{\sqrt{\bar{a}_i^2(T) + \bar{a}_i^2(T)}}\right) - 2\pi f_0 T.$$

With the right choice of the beginning of the pulse, the phase of the signal $\psi_i$ will be almost uniform within the clock interval. Minor phase fluctuations due to noise will be observed. If there is a delay in the beginning of the pulse, at the moment of transition from one channel symbol to another there will be a phase jump equal to the phase difference of the transmitted channel symbols. To determine the transition from one channel symbol to another, it is necessary to clearly define the moment of the jump. To do this, it is necessary to form a signal for the difference in phase values across the sampling interval. At the time of a phase jump, a single, substantially non-zero jump will be observed. The moment of the jump will determine the beginning of the channel symbol. The error of the start pulse adjustment will not exceed the sampling interval. The scheme that implements this algorithm is shown in Fig. 1.
Algorithm adjustment of the reference generator. The proposed algorithm is intended to be used for determining the phase $\phi_0$ the intermediate results of the clock recovery system, namely the values $\psi_i$. Sampling of values is performed within certain limits of the channel symbol and averaging is performed. Then it is necessary to introduce a correction of the phase value taking into account the clock adjustment, namely, to add the obtained result to the phase increment due to the propagation delay $2\pi n T_s$, where $nT_s$ clock delay defined. Next, the area of ownership is determined $\phi_0$, as difference $\phi_0 = \tilde{\phi}_i - \phi_i$. The resulting value is used to adjust the reference oscillator. The scheme that implements this algorithm is shown in Fig. 2.

Phase averaging over $N$ values reduces the effect of phase fluctuations due to phase noise. To ensure accurate system operation in conditions of significant phase change in the channel, a preamble is needed, consisting of some sequence of channel symbols known on the receiving side. In the future, the system adjusts the phase difference of the received channel symbol and the phase reference value closest to the received value.
Coherent detection of two-dimensional digital modulation signals

Despite certain computational difficulties (many complex operations: multiplication, squaring, division at one clock interval), the proposed algorithms are still effective in terms of the use of computational power. This is due to the fact that the results obtained are used to provide two types of synchronization at once. In the phase adjustment and clock recovery algorithms, mutual effects are eliminated, despite the fact that the adjustment is carried out by phase error.

REFERENCES:

ЛИТЕРАТУРА: