Interference effect of impulse noise on noise immunity of communication and control channels in underground structures

Yu K Vyboldin, S V Borisov

Saint Petersburg Mining University, 2, 21 Line of V.O., Saint Petersburg, 199106, Russia

E-mail: Y.Vyboldin@mail.ru

Abstract: The interference effect of impulse noise on the noise immunity of underground communication systems is investigated. A comparative analysis of the noise immunity of an optimal demodulator of the discrete FM signals and of the system "wide band – limiter – narrow band", in the presence of impulse noise, has been carried out.

1. Introduction

The choice of the signal forming method for solution of the communicational and navigational problems in the underground mine is connected with the necessity of taking into account several contradicting factors. The most important among them is the necessity of the required long-range interaction assurance of the system and of the data transfer rate at the predetermined noise immunity. There are well-known notification systems that apply signal transfer through the rock massif and preserve operability in the alarm conditions. Such systems are applied for data transfer with the discrete frequency modulation (FM) signals. A small pass band of the underground medium and significant variation of the signal attenuation within the operating frequency band provide obtaining only a possibility of the code messages transmission about an emergency mode. Therefore, one of the basic problems remained is the mode choice of the signal being formed and its comprehension. The efficiency comparative assessment of the employed signal forming methods in the underground communication systems is represented in the paper [1], where, considering the influence of various industrial interference sources, a choice is made in favor of the discrete FM signals as well. During construction of a data transfer system through the rock massif, there is an opportunity to use the multiposition signals as well that permit one to increase considerably the communication efficiency [2, 3]. However, when there is the need to transfer signals at long distances exceeding 300m, as the noise level increases, it is recommended to use more simple discrete FM signals.

In the underground communication system, the discrete FM signals are often used for remote control of the power objects. In this case, an online control is expected to be carried out for a large amount of the process-dependent parameters being read out from various transducers distant from a data acquisition and processing device. In case the use of wire communication channels is impossible, the wireless data transfer systems are recommended. The essential feature of the data transfer lines used consists in their multiple channels; at that, the latter must have the binary number of channels corresponding to the transducers number in the system. High efficiency of the source information acquisition system could be achieved when making use of the multipositional FM signals.

It is well-known that impulse noise considerably effects the noise immunity of FM data communication systems. The review of research results on the problem has been carried out in paper [4]. The most effective method of impulse noise suppression, when using FM, is considered application of the limiter. But at the present time, the paths comprising limiters have been examined only from the aspect of the output energy responses. For example, it is known [5,6] that the limiter suppresses weak signal amplitude, the amplitudes ratio of the greater signal to the lesser signal at the output increases almost twice in relation to the corresponding ratio at the input. If this ratio is of the order of unity, then it is preserved at the output.

The purpose of this study involves the comparative analysis of the noise immunity of an optimal demodulator of the discrete FM signals and of the system "wide band – limiter – narrow band", in the presence of impulse noise.

2. Results and Discussions

Let us consider reception of a binary FM signals that are orthogonal in a strengthened sense [5]; in this case, let us suppose that the impulse noise appears once on an element of the signal, at a random time. In such conditions, the signal at the input of the receiver could be represented as follows:

$$Z^*(t) = U\,cos(\omega_r t + \varphi) + \nu_i \delta(t - t_i) + n(t), \tag{1}$$

$$U = \sqrt{2P_c}.$$

Here, U, φ – amplitude and a random initial phase of a useful signal, ν_i – a spectral density of impulse noise amplitudes, $n(t)$ – white noise, P_c – average power, w_r – frequency of r-th position.

Let us assess the noise immunity of the optimal demodulator, as applied to reception of a binary FM signals, under the influence of noise and impulse noise.

Let us approximate the pulse characteristic of the broadband path as follows:

$$g_0(t) = \frac{2}{\tau_0} cos\omega_0 t, \tag{2}$$

whereas outside the limits of this section, impulse response equals zero. Here, ω_0 – the average frequency (usually the receiver's intermediate frequency).

The received signal at the demodulator input can be determined using the Duhamel integral as:

$$Z^{'}(t) = \int_0^\infty Z^{''}(\tau) g_0(t - \tau) d\tau.$$

Provided that a harmonic signal with a rectangular envelope would be sent (the useful signal in (1)) to the input of bandpass filter with response (2), the envelope of the output filter effect would consist of three parts [5].

The first part determines the signal-setting process during time τ_0 where an amplitude and phase of the signal are time-varying. The second part, with duration of $(T - \tau_0)$, represents the established process that bears information about r-th position of the FM signal ($r = 1, 2$), and looks as follows:

$$Z_r(t) = U sin\frac{(\omega_0 - \omega_r)\tau_0}{2}\left[\frac{(\omega_0 - \omega_r)\tau_0}{2}\right]^{-1} cos\left(\omega_0 t - \varphi + \frac{(\omega_0 - \omega_r)\tau_0}{2}\right). \tag{3}$$

The third part, from T to $(T + \tau_0)$, describes attenuation of a useful signal, and is followed by the change of its amplitude to zero and phase change. So it is useful to use protective gaps between the elements of the signal to increase the noise immunity for inter-element interference, but while the transmission speed is reduced to $B_1 = {}^1\!/_{T + \tau_0} = (1/(1 + T))B$, where $B = {}^1\!/_{\tau_0}$ – the initial signal transmission rate. Taking into account the assumptions made, the received signal at the FM demodulator input looks as follows:

$$Z^{'}(t) = Z_r(t) + \sigma_i(t) U_i cos\omega_0(t - t_i) + N_c(t)\,cos\omega_0 t + N_s(t) sin\omega_0 t, \tag{4}$$

.

Here, $Z_r(t)$ is determined in accordance with (3), $\sigma_i(t)$ – switching function, $\sigma_i(t) = 1$ at $t_i \leq t \leq t_i + \tau_0$, $\sigma_i(t) = 0$ for the rest of t, t_i – the impulse noise emergence moment with uniform distribution in the range from zero to $(T - \tau_0)$, and $N_s(t)$ – quadrature components of the noise interference, U_i – the impulse noise amplitude.

Let us use a well-known optimal decision scheme for the discrete FM signals reception as the demodulator [5]. It is considered that the signal's q-th position has been received if

$$V_q^2 > V_r^2. \tag{5}$$

Here, V_q and V_r – envelopes of signals at the output of filters, being matched accordingly with q– th and r–th positions by the time the information part of the element T has been received when the signal of form (4) is applied to their input, $q \neq r, q, r = 1,2$.

The reception scheme according to the algorithm (5) is optimal for the case when the additive noise has the form of white noise. Synthesis of optimal decision rules for reception in the presence of only impulse noise leads to the need for preliminary nonlinear processing of the received signals before making a decision. Usually in this case a limiter is used. The way of optimal demodulation schemes syntheses in conditions of simultaneous impact of impulse and noise interference is currently unknown. In this connection, let us confine ourselves to a sub-optimal scheme that is a superposition of these optimal schemes. It will consist of a broadband path (this is a filter with an impulse response (2)), an amplitude limiter and a narrowband path (in our case this is a decisive scheme that realizes rule (5)). To evaluate the effectiveness of this scheme, it is necessary to compare its noise immunity with the interference immunity of an optimal FM demodulator in the presence of impulse noise.

Further, let us find the probability value of the optimal demodulator error, with the signal at the input of form (4), at presence of the white noise and impulse noise. In this case, each quadrature component of the algorithm (5), calculated for transmission of q -th position, consists of three additive components which may be defined as a useful signal, impulse noise, and fluctuating noise.

The dispersion's value of the r-th interference component, for the reception path number r, could be calculated as follows:

$$\sigma_r^2 = S_r^2 - \frac{1}{T}\left(\frac{2}{(\omega_1 - \omega_2)\tau}\right)^2 \left(S_{r1} - cos^2 \frac{(\omega_1 - \omega_2)\tau}{2}\right),$$

where

$$S_r = sin \frac{(\omega_0 - \omega_r)\tau_0}{2} \Big/ \frac{(\omega_0 - \omega_r)\tau_0}{2}, \quad S_{r1} = sin \frac{(\omega_r - \omega_i)\tau_0}{2} \Big/ \frac{(\omega_r - \omega_i)\tau_0}{2}.$$

Now, the interference components may be presented as $\sigma_r N_{cr}$ and $\sigma_r N_{sr}$. Here, N_{cr} and N_{sr} – independent normally distributed random values with zero means and unit dispersion.

In the capacity of the second version, let us consider noise immunity schemes with the limiter embedded between the broadband path and the decision-making device. Such scheme realizes the suboptimal algorithm of the discrete FM signals demodulation. Let us suppose that the value of the impulse noise amplitude significantly exceeds the signal amplitude, in such way that

$$\frac{U_i}{U} = \sqrt{\frac{T}{\tau_0}} \gg 1. \tag{6}$$

Taking into account the features of the limiter [4], let us suppose that under the condition (6) being met, the useful signal within the interval $t_i - (t_i + \tau_0)$ is fully suppressed by the impulse noise. The error probability value calculated, in this situation, is the upper bound for the error probability at FM reception, given the effect of the impulse noise and fluctuating noise. Given the assumption made, the signal being received at the FM demodulator input would look as follows:

$$Z'(t) = \big(1 - \sigma_i(t)\big)Z_r(t) + \sigma_i(t)U_i cos\omega_i(t - t_i) + N_c(t)cos\omega_0 + N_s(t)sin\,\omega_0, \tag{7}$$

When calculating the noise immunity, let us consider the limiter of the impulse noise with the threshold value equal to the useful signal amplitude. In this case, the useful signal and noise are not distorted, whereas the impulse noise amplitude is reduced down to the useful signal's amplitude. To do this, let us suppose that in [4] variable $U_i = U$ for $t_i \leq t < t_i + \tau_0$ and equal to 0 for others t.

The results of the error probability's calculations for the processing circuit without limiter (P_1) and with limiter (P_2), are presented in Table 1. The considered case was for the discrete FM signal with parameters

$$\frac{\omega_1 - \omega_2}{2\pi} = 100\ hz, \qquad \frac{\omega_0}{2\pi} = 500\ khz, \quad T = 0.01\ s.$$

Let us determine the losses using the error probability in the presence of impulse noise comparatively to the losses of the optimal demodulator under the conditions of the action of only white noise and with error probability. It is well-known that the error probability of such demodulator is defined by the expression

$$P = \tfrac{1}{2} exp\,(-H^2/2).$$

Here $H^2 = {}^{P_c T}\!/_{\mathrm{V}^2}$. – the signal-to-noise ratio. Similarly, let us suppose that the interference's energy to noise ratio is $H_i^2 = {}^{P_i \tau_0}\!/_{\mathrm{V}^2}$. Hereby let us assume that the condition $H_i^2/H^2 \geq 1$ is fulfilled. Hence, the required probability $P = 0{,}01$ will be achieved at $H^2 = 7.824$. The error probabilities of the demodulator under study was calculated at $\tau_0 = 10^{-3}$ $(F = 1000\ hz)$, and for $(F = 10000\ hz)$ and results are shown in tables 1, 2.

Table 1. $(F = 1000$ hz)

H_i^2	0	3.912	7. 824	12.684	39,12	78,24
P_1	0.011	0.007	0.033	0.066	0.157	0.244
P_2	0.011	0.0295	0.235	0.0235	10235	0.0235

Table 2. $\tau_0 = 10^{-4}$ $(F = 10000\ hz)$

H_i^2	0	7.824	78.24	156.48	391.2	782.4
P_1	0.01	0.015	0.04	0.052	0.142	0.226
P_2	0.01	0.018	0.018	0.018	0.018	0.018

One may note a good agreement between the results of modeling and theoretical assumes when $H_i^2 = 0$. For the scheme without the limiter, the noise immunity is slowly deteriorating as the value of H_i^2 is rising. The threshold value for the ratio of the impulse noise's energy to the noise intensity at which communication is impossible $P_1 > 0.1$ is

$$H_{i\,thres}^2 = \tfrac{1}{2} H^2 (\tfrac{T}{\tau_0}).$$

3. Conclusion

The use of the limiter can significantly improve the noise immunity of reception in the presence of impulse noise. If condition (8) is satisfied, the error probability increases only twofold. Thus, circuits with a limiter can be successfully used under conditions of strong pulsed interference when transmitting discrete FM signals.

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4. References

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