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THE ANTI-JAMMING ABILITY OF SIGNAL TRANSMISSION WITH PULSE-CODE MODULATION OVER OPTICAL COMMUNICATION LINKS

by

N. M. Pavlov, L. A. Mayorova

FOREIGN TECHNOLOGY DIVISION

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А а	*А а*	A, a	Р р	*Р р*	R, r
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В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

THE ANTI-JAMMING ABILITY OF SIGNAL TRANSMISSION WITH PULSE-CODE MODULATION OVER OPTICAL COMMUNICATION LINKS

N. M. Pavlov, L. A. Mayorova

The article[1] analyzes signal reception with pulse-code modulation over optical communication links with direct read-out by using a filter at the output of the photodetector with a characteristic which provides a pulse spectrum which varies according to the COS^2X law. It is shown that the anti-jamming ability with this method of reception is close to the potential anti-jamming ability when reception is by the photon count method.

In a number of published works [1-3] it is shown that for optimum detection of optical signals it is necessary to use short light pulses. However, in transmitting signals with IKM [pulse-code modulation] pulse gating and the counting of photons in a short time interval are necessary.

Direct counting of photons at high velocity presents certain difficulties; therefore it is desirable to use reception methods which do not require the direct counting of the photons but whose anti-jamming ability will be near the potential.

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[1]Submitted 28 February 1973.

In this work the reception method is examined in accordance with the block-diagram presented in Fig. 1. As shown below this method of reception corresponds to the photon counting method and provides the potential anti-jamming ability with a pulse length tending to zero and with the signal spectrum at the input of the resolver determined by the expression

$$S(\omega) = en\cdot e^{-j\omega t_0}\cdot \cos^2\frac{\pi\omega}{2\omega_{гр}}, \qquad (1)$$

where e is the electron charge, n is the number of photoelectrons in the pulse, ω is the present frequency, $\omega_{гр}$ is the upper edge frequency of the spectrum, t_0 is the signal time lag at the output of the filter.

Since in actuality the pulse length will have a finite value, it is necessary to determine the anti-jamming ability of the OLS [optical communications link] with the presence of a finite pulse length.

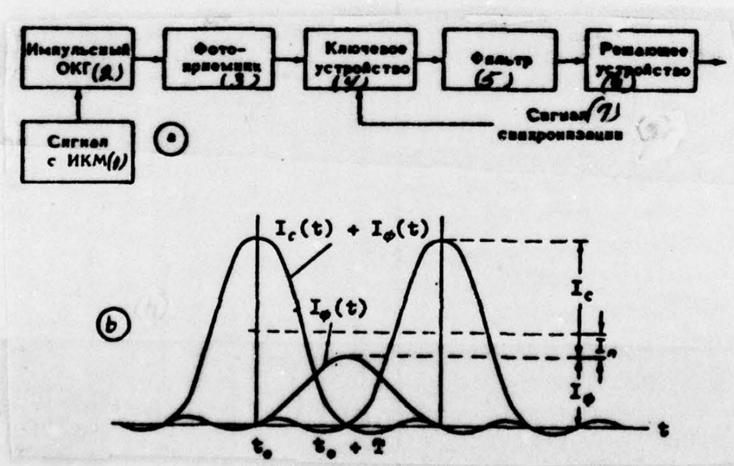

Fig. 1.

KEY: (1) Signal with IKM [pulse-code modulation; (2) Pulse laser; (3) Photodetector; (4) Keying device; (5) Filter; (6) Resolver; (7) Synchronization signal.

For simplifying calculations it is assumed that:

- the source of the light radiation works in a pulsing mode;

- at the light source output the light pulses have a rectangular form;

- the photodetector is inertialess and all frequency limitations are determined by the filter at the output of the photodetector;

- at the output of the photodetector a keying device (KU) is installed which allows a signal to pass only in the pusle length interval.

Since the signal pulse at the output of the filter passes through zero at the point in time $\pm(T_{zp} + t_0)$ (Fig. 1), where $T_{zp} = \frac{2\pi}{\omega_{zp}}$, then the pulse repetition interval T is assumed to be equal to T_{zp}. Therefore the greatest possible pulse length is $T_{u\,max} = T_{zp}$.

According to [4], the correlation function of the transient photoelectric current at the output of the inertialess photodetector is written as:

$$K(t_1,t_2) = e^2\lambda(t_1)\cdot\delta(t_2 - t_1) + e^2\lambda(t_1)\,\lambda(t_2), \qquad (2)$$

where $\lambda(t)$ is the instantaneous photoelectron flux density; e is the electron charge; $\delta(t)$ is the delta-function.

Examining first the passing of one pulse along the OLS we may write

$$\lambda(t) = \lambda_0 K(t),$$

where λ_0 is the instantaneous photoelectron flux density within the limits of the pulse length;

$$K(t) = \begin{cases} 1 \text{ - within the limits of the pulse length} \\ 0 \text{ - outside the limits of the pulse length.} \end{cases}$$

The current pulse spectrum at the input of the filter may be shown as:

$$S(\omega)_{\text{вх}} = I_0 T_{и} \frac{\sin \frac{\omega T_{и}}{2}}{\frac{\omega T_{и}}{2}}, \qquad (3)$$

where I_0 is the current magnitude in the pulse. It is obvious that $I_0 T_{и}$ = en, where n is the number of photoelectrons in the pulse.

In [5] it is shown that for ensuring the anti-jamming ability of the reception of the pulse signals it is advisable to have the pulse spectrum which conforms to expression (1) at the output of the receiver.

From expressions (1) and (3) is determined the transmission characteristic of the filter:

$$K(\omega) = \frac{\omega T_{и}}{2} \, \frac{\cos^2 \frac{\pi\omega}{2\omega_{гр}}}{\sin \frac{\omega T_{и}}{2}} \, e^{-j\omega t_0}. \qquad (4)$$

To estimate the anti-jamming ability of the reception method under consideration, in relation to the on-off time ratio, we will assume the probability of error as constant for all values

$$\alpha = \frac{T_{и}}{T_{и\,max}}. \qquad (5)$$

It is possible to show that in expressions (1), (3) and (4) the magnitude of the signal at the input of the resolver (RU) is independent of α and is proportional to the number of photoelectrons.

The probability of error in receiving a "1" is determined by the expression

$$P_{\text{ош}_1} = \int_{-\infty}^{-(\text{Э}_{ф}-\text{Э}_{п})} W_1(x)\,dx,$$

where $W_1(x)$ is the probability density of noise distribution at input of the resolver at point in time t_0 in transmitting a "1"; I_c is the magnitude of the useful signal at the input of the resolver (RU) at point in time t_0; I_n is the threshold value of the RU (See Fig. 1b).

The probability of error in receiving a "0" is determined from the expression:

$$P_{ош_0} = \int_{I_n}^{\infty} W_0(x)\,dx,$$

where $W_0(x)$ is the probability density of noise distribution at point in time $T + t_0$ in receiving a "0".

The probability density distribution of noise at the output of the filter is assumed to be normal.

Considering the current pulse at the outlet of the keying device as the sum of the current which is caused by the signal, and of the current which is caused by the background radiation, we may write:

$$P_{ош_1} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{-\frac{I_c - I_n}{\sqrt{D_1(\alpha) + D_\phi(\alpha)}}} e^{-x^2/2}\,dx; \quad P_{ош_0} = \frac{1}{\sqrt{2\pi}} \int_{\frac{I_n}{\sqrt{D_0(\alpha) + D_\phi(\alpha)}}}^{\infty} e^{-x^2/2}\,dx,$$

where $D_1(\alpha)$ is the noise dispersion which is caused by the signal pulse at point in time t_0 in receiving a one; $D_\phi(\alpha)$ is the noise dispersion which is caused by the background radiation at point in time t_0; $D_0(\alpha)$ is the noise dispersion which is caused by the useful signal at point in time $t + t_0$ in receiving a zero.

Assuming that $P_{ош_1} = P_{ош_0}$, we obtain:

$$\frac{I_c(\alpha)}{I_c(0)} = \sqrt{\frac{D_0(\alpha)}{D_1(0)} + \frac{D_\phi(\alpha)}{D_1(0)}} + \sqrt{\frac{D_1(\alpha)}{D_1(0)} + \frac{D_\phi(\alpha)}{D_1(0)}}. \qquad (6)$$

Expression (6) determines the anti-jamming ability of reception as a function of α, since the ratio $\frac{I_c(\alpha)}{I_c(0)}$ is the ratio of necessary signal power at the input of the photodetector.

For estimating the anti-jamming ability it is necessary to compute $D(\gamma\alpha)$ at the points in time of gating by the resolver.

The noise dispersion at the output of the filter may be determined according to [6] by the formula:

$$D_{ш}(t) = \int_{-\infty}^{t}\int_{-\infty}^{t} G(t_1 - \tau_1)\cdot G(t_2 - \tau_2) K_{ш}(\tau_1, \tau_2)\, d\tau_1 \cdot d\tau_2, \qquad (7)$$

where $G(t)$ is the pulse response of the filter.

Substituting the expression for $K_{ш}(\tau_1\tau_2)$ into formula (7) we obtain the time dependence of dispersion at the output of the filter:

$$D_{ш}(t) = e^2 \lambda_0 \int_{-\infty}^{t} G^2(t - \tau)\, d\tau. \qquad (8)$$

with $t > \frac{T_{и}}{2}$

$$D_{ш}(t) = e^2 \lambda_0 \int_{-T_{и}/2}^{T_{и}/2} G^2(t - \tau)\, d\tau. \qquad (8')$$

The pulse response of the filter is determined on the basis of formula (4):

$$G(t) = \frac{4}{\pi T_{ср}} \int_0^{\pi/2} 2\alpha x \frac{\cos^2 x}{\sin 2\alpha x} \cos \gamma x\, dx. \qquad (9)$$

The integral in expression (9) is not tabular. Employing the analysis of the integrand in a power series we obtain:

$$G(t) = \frac{1}{T_{ср}} \left\{ h_0 + h_2\gamma^2 + h_4\gamma^4 + \ldots \right\}, \qquad (10)$$

where

$$h_m = \frac{4(-1)^{m/2}}{\pi \cdot m!} \sum_{j=m/2}^{p/2} \frac{\left(\frac{\pi}{2}\right)^{2j+1} d_{2j-m}}{2j+1},$$

$$d_m = b_m - \sum_{j=1}^{m/2} c_{2j} d_{m-2j}, \quad b_m = \frac{2^{m-1}(-1)^{m/2}}{m!},$$

$$c_{2j} = \frac{(-1)^j (2\alpha)^{2j}}{(2j+1)!}. \qquad (11)$$

p/2 is the number of terms in expression (10).

Substituting expression (9) into (8'), we obtain:

$$D(t) = \frac{e^2 n}{T^2_{sp}} \left\{ \sum_{j=0}^{p/2} \frac{g_{2j}(2\alpha)^{2j}}{2j+1} + \sum_{j=1}^{p/2} \frac{\gamma^{2j}}{(2j)!} \left[\sum_{l=j}^{p/2} g_{2l}(2\alpha)^{2l-2j} \prod_{i=0}^{l-j-2} (2i-1) \right] \right\}, \qquad (12)$$

where $g_m = \sum_{j=0}^{p/2} h_{2j} h_{m-2j}$.

From the analysis of expression (12) it is evident that with $t = t_0$ the value included in the braces characterizes a decrease in anti-jamming ability in comparison with the photon counting method (with $\alpha = 0$, corresponding to the photon counting method, the value included in the braces is equal to 1 with $t = t_0$).

The $D(\gamma,\alpha)$ computations were made on a "MIR" computer. The results of the $D(\gamma, \alpha)$ computation are presented in Fig. 2.

It is possible to show that in expression (6)

$$\frac{D_\phi(\alpha)}{D_1(0)} = \frac{D_1(\alpha)}{D_1(0)} k\alpha,$$

where $k = \frac{n_\phi}{n_c}$; n_ϕ is the mean number of background photoelectrons in interval T; n_c is the mean number of signal photoelectrons per pulse.

Figure 3 shows the relationship of the anti-jamming ability of the scheme presented in Fig. 1 to the values of α and k.

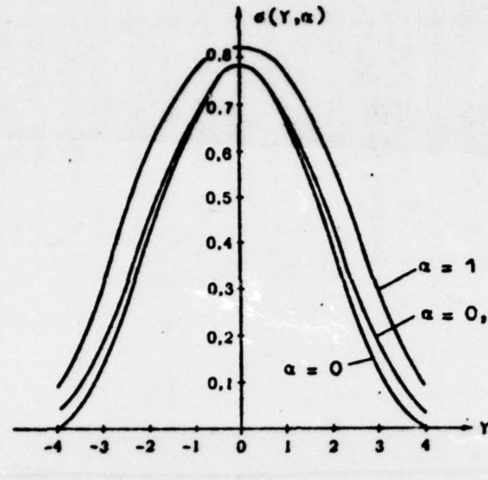

Fig. 2.

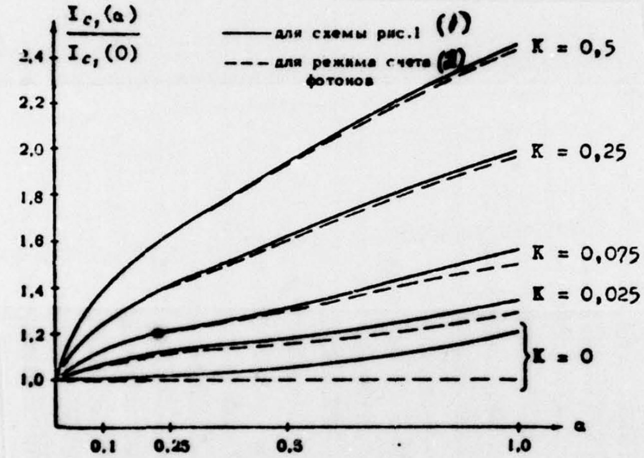

Fig. 3.

KEY: (1) for the scheme in Fig. 1; (2) for the photon counting method.

The results obtained allow us to conclude that the method of reception for the scheme in Fig. 1 possesses anti-jamming ability near the potential. The decrease in anti-jamming ability in comparison with the potential amounts to no more than 0.8 dB. The use of a gas laser in synchronized mode, a semiconductor laser, or a light-diode in the pulse working mode and a method of reception according to the scheme in Fig. 1 permit us to obtain an anti-jamming ability near the potential.

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