ALGORITHM OF MAIN SYSTEM PARAMETERS ESTIMATION OF COMPOSITE FREQUENCY SELECTIVE CHANNEL WHICH UTILIZES DIFFERENT TYPES OF PAM-N SIGNALS IN THE PRESENCE CROSSTALK

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A new phenomenological method and algorithm implementation for estimating the system parameters of a composite communication channel with memory (capacity at a given bit error rate value, the required signal-to-noise ratio for implementation etc) are developed in the paper. The considered in the paper channel consists of frequency selective information channel while a multi-position amplitude-pulse signal is transmitting, which can be either unipolar or bipolar, as well as interfering frequency selective channels through which the same type signals are transmitted. The obtained method and algorithm implementation for major case of frequency selective channel are evolution of previously private results within the framework of the resolution time theory for broadband communications channels. The results can be interesting to specialist who develop the communication systems in automotive, air transport area and broadband wired data transmission systems. A distinctive feature of the developed method and algorithm implementation is that, firstly, they have polynomial complexity, which is independent of the size of the channel alphabets of the multi-position amplitude-pulse signals. The obtained method and algorithm implementation has the following restriction: the start time of transmission of each signal and transmission rate are the same.

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Introduction

Currently, the evolution of society toward a new stage, namely, the information society is most pronounced [1-3]. It is worth noting that the dynamics of such processes is increasing exponentially, which is clearly visible in the volume of scientific publications, which is also growing exponentially by year [1, 4]. In particular, this is due to the widespread use of artificial intelligence to solve various types of problems, particularly in:

a) ocially significant areas:

- personalized education [5-7];
- implementation of "smart" libraries and information and analytical systems [1, 6];
- labor market analysis to determine current labor market needs [8]

b) in the area of GDP:

– analysis of user needs when consuming services and services offered by GDP, followed by forecasting them in the context of rapidly changing market conditions [9, 10];

– creating systems for generating solutions to support the operation of critical sectors of the economy [11].

This leads to a significant increase in the requirements for data transmission infrastructure between data center nodes [12, 13], which makes a significant contribution to their overall performance [14].

At the same time, developers of data transmission systems (DTS) between data center nodes face with a number of mutually exclusive, simultaneously acting conditions and constraints when constructing them, namely [15-21]:

– the need to reduce the required energy per bit of transmitted information while ensuring a given reliability of the transmitted message;

– he need to increase the data transfer rate, including the case when severe intersymbol interference (ISI) is observed and produced by dispersion properties of the propagation medium;

– the need to reduce the impact of crosstalk on information signal on the receive end, even in the case with a denser spatial packing of potential crosstalk sources;

– the need of receiver development that are technologically sufficiently simple;

– the capacity limitation of DTS due to the imperfections of the receiving devices and the channel dispersion which produce ISI.

The analysis of recent papers [22-25] shows that bipolar signals with *n* multiposition pulse amplitude modulation (bipolar PAM-n-signals) are most widespread utilized in data transmission for such wired DTS, due to the fact that its practical implementation has the least complexity and lower value of required signal to noise ratio. However, the results of papers [26, 27] indicate the fact that, in some wired DTS unipolar PAM-n signals are used. Taking into account the above presented information and the results of papers [15,16], it becomes obvious to find out an optimal solution to the above-mentioned problems requires the development of a fundamentally new approach to analyzing the processes that affect on signal integrity of received PAM-n-signal on the output of frequency selective channel (FSC) in the presence of crosstalk, when information and interfering signals can be simultaneously of both types unipolar and bipolar.

Based on result [15-19] the solution of presented above problem would be obtained within the framework of theory of resolution time. Therefore, in this case the complexity of resulting algorithm would be linear in relation to the number of crosstalk sources and independent of the alphabet size of the signals. In the considered case, we will limit ourselves to the case where the duration of the channel symbols (CS) of the information and interfering signals are the same, and the start time of their transmission and channel symbol durations (CSD) coincide, which is due to the fact that in data processing centers, sufficiently small distances are used for transmitting information, where this limitation is met. In addition, such restrictions may be applied in the field of DTS used in transport.

So, the aim is to develop an algorithm for main system parameters estimation of complex FSC (CFSC) implementation the simulating the function of a wired baseband telecommunications system with linear complexity in relation to the number of crosstalk sources and independent of the alphabet size of two possible used types of PAM-n-signals.

1 Problem Statement

To achieve the declared aim, the features for real wired broadband communication systems mentioned in the paper [16] in problem statement section were taken into account for considered case in this paper. The most important of them is that the consideration is made only the primary impaction of crosstalk.

Besides analyzing the previous results in the field of considered problem [16] it becomes obvious that the following private tasks should be solved taking into account:

1) The mathematical model for the considered case in this paper should be obtained by math models modification presented in papers [15, 16] taking into account all their limitations.

2) Based on modified math model expressions and equations should be obtained for two cases. The first of it is expression for greatest settling error (GSE) estimation at the output composite FSC in the dependence of CSD and given number of transmitted channel symbols (NTCS). And the second of it is the expression for GSE for given values of time shift at which information about the transmitted CS is retrieved for given CSD and NTCS. Two types of equations, the first of it for greatest settling time estimation when GSE coincide to permissible error (PE) of information parameter of signal on the receive end and the second of it for greatest time shift calculation for given value of CSD and PE while GSE coincide to PE for the information parameter of information PAM-*n*-signal at the output composite FSC.

3) Expression for estimating the dependence of effective memory for considered math model on CSD.

4) Construct the algorithm implementation for main system parameters estimating for math model of considered channel utilizing results of papers [15, 16].

2 Problem Solution

The math model of composite FSC for considered type of wired communication systems has the same structure diagram as presented in papers [15, 16]. Therefore, each functional block of structure diagram has the same functional purpose as in the papers [15, 16]. The modified structural diagram of considered composite FSC presented in Fig. 1.

In Fig. 1 the following designation are used:

- Math operations: $*$ is convolution;

- Special functions: $\delta(t)$ is Dirac function;
- Variables and sets: τ_s is CSD; $i \in \overline{1,N}$ and N are ordinal number and number of interfering crosstalk sources, respectively; l is NTCS; $M_r \in \mathbf{M}$ and $A_{i,r} \in \mathbf{A}_i$ are amplitudes of r^th pulse of transmitted signals with n_0 and n_i multiposition amplitude modulation of baseband pulses through information FSC and *i*-th interfering FSC (PAM-n_0- signal and PAM-n_i- signal, respectively) [15,16]; $\Delta T_\text{s} \in (0;\tau_\text{s})$ is the time shift in the retrieving moment on the received end; $\mathbf{M}$ and $\mathbf{A}_i$ are sets, which elements define of PAM-n_0- and PAM-n_i- signals signal constellations (SC), respectively; k_{los_0} and k_{los_i} are losses introduced by the propagation medium that defines information FSC (InFSC) and ith interfered FSC (*i*-IfFSC), respectively; $k_\text{A} = k_{\text{A}_1} k_{\text{A}_2}$ is gain of amplifier, where $k_{A_1} = k_{\text{los}_0}{}^{-1}$;

$$k_{\text{A}_2} = \begin{cases} \dfrac{\max g_{\text{sh}_0}(t)}{\max P(t)} \text{ if } \max g_{\text{sh}_0}(t) \ge \max P(t); \\ 1 \text{ if } \max g_{\text{sh}_0}(t) < \max P(t). \end{cases} \tag{1}$$

- Responses of FSC elements: $g_{\text{sh}_0}(t)$ and $g_{\text{sh}_\text{i}}(t)$ are impulse responses of shapers for InFSC and *i*- IfFSC, respectively; $P(t)$ and $I_i(t)$ are the responses of InFSC and *i*-IfFSC on $g_{\text{sh}_0}(t)$ and $g_{\text{sh}_\text{i}}(t)$, respectively; $h_0(t)$ and $h_i(t)$ are impulse responses of InFSC and *i*-IfFSC, respectively; $P'(t-(r-1)\tau_\text{s}) = k_{\text{A}_2} P(t-(r-1)\tau_\text{s})$; $I_i'(t-(r-1)\tau_\text{s}) = k_\text{A} k_{\text{los}_i} I_i(t-(r-1)\tau_\text{s})$;
- Process: $n(t)$ is AWGN; $n'(t) = k_\text{A} n(t)$ is normalized AWGN at the output of amplifier.

The decision device recovers each symbol ($d = \overline{1,l}$) in sequence of transmitted PAM-n_0-signal on the receive end in according the following rule

$$M_{\text{rec}_d} = M_p \big|_{p=p'}, \tag{2}$$

where $p' \in \overline{1,n_0} : f(p',d) = \min\limits_{p \in \overline{1,n_0}} \left| s_\text{sp}(d\tau_\text{s}) - M_p \right|$.

The implementation of the method and algorithm implementation for considered general case is achieved by the following below modifications.

SC $\mathbf{M}$ or $\mathbf{A}_i$ are defined as follows, when PAM-n_0-signal is a bipolar signal:

$$\mathbf{M} = \left\{ M_{\text{sc}_k} \right\}_{k=1}^{n_0} = \left\{ M_{\text{sc}_k} = \left(k_0 - \|n_0/2\| - 0.5(1-n_0 \bmod 2)\right) \Delta M_\text{st}, k_0 = \overline{1,n_0} \right\}, \tag{3}$$

or

$$\mathbf{A}_i = \left\{ A_{\text{sc}_{k_i,i}} \right\}_{k_i=1}^{n_i} = \left\{ A_{\text{sc}_{k,i}} = \left(k_i - \|n_i/2\| - 0.5(1-n_i \bmod 2)\right) \Delta A_{\text{st}_i}, k_i = \overline{1,n_i} \right\}. \tag{4}$$

In this case according to results of paper [16]:

$$\begin{aligned} &\left| M_{\text{sc}_1} \right| = \left| M_{\text{sc}_{n_0}} \right| = M_\text{max}; \\ &\left| A_{\text{sc}_{1,i}} \right| = \left| A_{\text{sc}_{n_i,i}} \right| = A_{\text{max}_i}. \end{aligned} \tag{5}$$

And when considered PAM-*n*- signal is a unipolar signal, then set $\mathbf{M}$ or $\mathbf{A}_i$ is defined as follows

$$\mathbf{M} = \left\{ M_{\text{sc}_k} \right\}_{k=1}^{n_0} = \left\{ M_{\text{sc}_k} = k \Delta M_\text{st} + M_\text{sh}, k = \overline{1,n_0} \right\} \tag{6}$$

or

$$\mathbf{A}_i = \left\{ A_{\text{sc}_{k_i,i}} \right\}_{k_i=1}^{n_i} = \left\{ A_{\text{sc}_{k,i}} = k_i \Delta A_\text{st} + A_{\text{sh}_i}, k_i = \overline{1,n_i} \right\} \tag{7}$$

In this case according to results of paper [15]:

$$\begin{aligned} &M_{\text{sc}_1} = M_\text{min}; M_{\text{sc}_{n0}} = M_\text{max}; \\ &A_{\text{sc}_{1,i}} = A_{\text{min}_i}; A_{\text{sc}_{n_i,i}} = A_{\text{max}_i}, \end{aligned} \tag{8}$$

Here ΔM_st and ΔA_{st_i} are step between adjacent values of SC elements of PAM-n_0- and PAM-n_i- signals, respectively; $n_\bullet \bmod 2$ is division with remainder; M_sh and A_{sh_i} are SC amplitude shift due unipolar signal is used.

To obtain the solution for the second of the stated tasks let's analyze the expression for *d*-th channel symbol settling error $\Delta_\text{set}(d\tau_\text{s})$ obtained in papers [15, 16]. Since the structure of considered FSC are the same as in the papers [15, 16] and the expression for *d*-th channel symbol settling error $\Delta_\text{set}(d\tau_\text{s})$ obtained in papers [15, 16] coincide so for considered structure of FSC in this paper the desired expression for $\Delta_\text{set}(d\tau_\text{s})$ in the absence of AGWN and $\Delta T_\text{s} = 0$ has the following form

$$\Delta_\text{set}(d\tau_\text{s}) = \sum_{r=1}^{d} \left[M_r P_{r,d}(\tau_\text{s}) + \sum_{i=1}^{N} A_{i,r} I_{i,r,d}(\tau_\text{s}) \right] - M_d. \tag{9}$$

where $P_{r,d}(\tau_\text{s}) = P'((d-r+1)\tau_\text{s})$, $I_{i,r,d}(\tau_\text{s}) = I_i'((d-r+1)\tau_\text{s})$.

Taking into account approach for calculation combinations of amplitude values presented in papers [15,16] for two types of PAM-n-signals to obtain the expression for GSE in the presence of crosstalk $\Delta_\text{max}(\,.\,) = \max \left| \Delta_\text{set}(\,.\,) \right|$ for considered case let's modify the equality (9) in the following way:

$$\left|\Delta_{\text{set}}\left(d\tau_{\text{s}}\right)\right| = \left| \underbrace{\sum_{z_1=1}^{d-1} F_+\left(M_{z_1} P_{z_1,d}\left(\tau_{\text{s}}\right)\right) + F_+\left(M_{d'}\left(P_{d',d'}\left(\tau_{\text{s}}\right)-1\right)\right)}_{\left(C_+\left(\tau_{\text{s}},d\right)\geq 0\right)\vee C'_+\left(\tau_{\text{s}},d\right)} + \underbrace{\sum_{i_1\in N_1}\sum_{r=1}^{d} F_+\left(A_{i_1,r} I_{i_1,r,d}\left(\tau_{\text{s}}\right)\right)}_{S_+\left(\tau_{\text{s}},d\right)\geq 0} + \right.$$

$$+ \underbrace{\sum_{i_2\in N_2}\sum_{r=1}^{d} F_+\left(A_{i_2,r} I_{i_2,r,d}\left(\tau_{\text{s}}\right)\right)}_{D_+\left(\tau_{\text{s}},d\right)} + \underbrace{\sum_{i_3\in N_2}\sum_{r=1}^{d} F_-\left(A_{i_3,r} I_{i_3,r,d}\left(\tau_{\text{s}}\right)\right)}_{D_-\left(\tau_{\text{s}},d\right)} +$$

$$\left. + \underbrace{\sum_{z_2=1}^{d-1} F_-\left(M_{z_2} P_{z_2,d}\left(\tau_{\text{s}}\right)\right) + F_-\left(M_{d''}\left(P_{d'',d''}\left(\tau_{\text{s}}\right)-1\right)\right)}_{\left(C_-\left(\tau_{\text{s}},d\right)\leq 0\right)\vee C'_-\left(\tau_{\text{s}},d\right)} + \underbrace{\sum_{i_4\in N_1}\sum_{r=1}^{d} F_-\left(A_{i_4,r} I_{i_4,r,d}\left(\tau_{\text{s}}\right)\right)}_{S_-\left(\tau_{\text{s}},d\right)\leq 0} \right|. \quad (10)$$

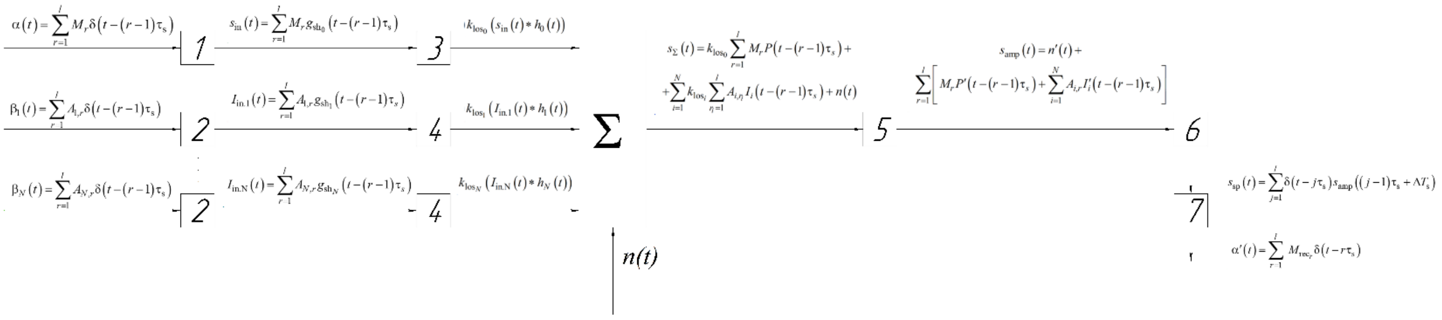

Fig. 1. Block diagram of a considered FSC. Designation: 1 – shaper in InFSC; 2 – shaper in *i*-IfFSC; 3 – InFSC; 4 – *i*-IfFSC; 5 – amplifier; 6 – sampler; 7 – decision device

In the expression (10) the following notations are used: $F_+(x)=|x|\operatorname{sgn}(\operatorname{sgn}(x)+1)$; $F_-(x)=|x|\operatorname{sgn}(\operatorname{sgn}(x)-1)$; $\operatorname{sgn}(x)$ is a signum function; $d'=d''=d$; $C_+(\tau_{\text{s}},d)$ and $C_-(\tau_{\text{s}},d)$ are used when PAM-n_0-signal is a bipolar signal, in the case when PAM-n_0-signal is a unipolar signal $C'_+(\tau_{\text{s}},d)$ and $C'_-(\tau_{\text{s}},d)$ are used; N_1 and N_2 are sets of ordinal numbers of interfering bipolar and unipolar PAM-signals, respectively.

Following the method, obtained in the papers [15, 16], it becomes obvious that the realization of the following equation $\forall\tau_{\text{s}},\forall d:\left|\Delta_{\text{set}}\left(d\tau_{\text{s}}\right)\right|\to\max$ can be ensured under the following set of conditions:

- when bipolar PAM-n_0-signal is used:

$$\begin{gathered}\left(C_+\left(\tau_{\text{s}},d\right)\to\max\right)\wedge\left(S_+\left(\tau_{\text{s}},d\right)\to\max\right)\wedge\left(D_+\left(\tau_{\text{s}},d\right)\to\max\right)\wedge\\ \wedge\left(\left|C_-\left(\tau_{\text{s}},d\right)\right|=0\right)\wedge\left(S_-\left(\tau_{\text{s}},d\right)=0\right)\wedge\left(\left|D_-\left(\tau_{\text{s}},d\right)\right|\to\min\right)\end{gathered};\quad(11)$$

or

$$\begin{gathered}\left(C_+\left(\tau_{\text{s}},d\right)=0\right)\wedge\left(S_+\left(\tau_{\text{s}},d\right)=0\right)\wedge\left(D_+\left(\tau_{\text{s}},d\right)\to\min\right)\wedge\\ \wedge\left(\left|C_-\left(\tau_{\text{s}},d\right)\right|\to\max\right)\wedge\left(\left|S_-\left(\tau_{\text{s}},d\right)\right|\to\max\right)\wedge\left(\left|D_-\left(\tau_{\text{s}},d\right)\right|\to\max\right)\end{gathered};\ (12)$$

- when unipolar PAM-n_0-signal is used:

$$\begin{gathered}\left(C'_+\left(\tau_{\text{s}},d\right)\to\max\right)\wedge\left(S_+\left(\tau_{\text{s}},d\right)\to\max\right)\wedge\left(D_+\left(\tau_{\text{s}},d\right)\to\max\right)\wedge\\ \wedge\left(\left|C'_-\left(\tau_{\text{s}},d\right)\right|\to\min\right)\wedge\left(S_-\left(\tau_{\text{s}},d\right)=0\right)\wedge\left(\left|D_-\left(\tau_{\text{s}},d\right)\right|\to\min\right)\end{gathered};\ (13)$$

or

$$\begin{gathered}\left(C'_+\left(\tau_{\text{s}},d\right)\to\min\right)\wedge\left(S_+\left(\tau_{\text{s}},d\right)=0\right)\wedge\left(D_+\left(\tau_{\text{s}},d\right)\to\min\right)\wedge\\ \wedge\left(\left|C'_-\left(\tau_{\text{s}},d\right)\right|\to\max\right)\wedge\left(\left|S_-\left(\tau_{\text{s}},d\right)\right|\to\max\right)\wedge\left(\left|D_-\left(\tau_{\text{s}},d\right)\right|\to\max\right)\end{gathered}.\ (14)$$

The analyses of conditions (11) – (14) allow us to formulate the following requirements for the multipliers values of the from which the terms of the polynomial are formed with satisfaction the conditions listed above. Therefore, the values of multipliers for bipolar PAM-n_0-signal are presented in Table 1 and for unipolar PAM-n_0-signal – in Table 2.

Table 1

Multipliers values of the at which (11) and (12) are meet true

Considered multiplier	Multiplier values			
	condition (11)		condition (12)	
	variant 1	variant 2	variant 1	variant 2
M_{z_1}	M_{sc_1}	$M_{\text{sc}_{n_0}}$	M_{sc_1}	$M_{\text{sc}_{n_0}}$
M_{z_2}				
$M_{d'}$				
$M_{d''}$				
$A_{i_1,r}$	$A_{\text{sc}_{1,i}}$	$A_{\text{sc}_{n_i,i}}$	$A_{\text{sc}_{1,i}}$	$A_{\text{sc}_{n_i,i}}$
$A_{i_4,r}$				
$A_{i_2,r}$	$A_{\text{sc}_{n_i,i}}$		$A_{\text{sc}_{1,i}}$	
$A_{i_3,r}$	$A_{\text{sc}_{1,i}}$		$A_{\text{sc}_{n_i,i}}$	
$P_{z_1,d}(\tau_\text{s})$	< 0	≥ 0	≥ 0	< 0
$P_{z_2,d}(\tau_\text{s})$				
$P_{d',d'}(\tau_\text{s})-1$				
$P_{d'',d''}(\tau_\text{s})-1$				
$I_{i_1,r,d}(\tau_\text{s})$				
$I_{i_4,r,d}(\tau_\text{s})$				
$I_{i_2,r,d}(\tau_\text{s})$	≥ 0			
$I_{i_3,r,d}(\tau_\text{s})$	< 0			

Table 2

Multipliers values of the at which (13) and (14) are meet true

Considered multiplier	Multiplier values			
	condition (13)		condition (14)	
	variant 1	variant 2	variant 1	variant 2
M_{z_1}	$M_{\text{sc}_{n_0}}$		M_{sc_1}	
$M_{d'}$				
M_{z_2}	M_{sc_1}		$M_{\text{sc}_{n_0}}$	
$M_{d''}$				
$A_{i_1,r}$	$A_{\text{sc}_{1,i}}$	$A_{\text{sc}_{n_i,i}}$	$A_{\text{sc}_{n_i,i}}$	$A_{\text{sc}_{1,i}}$
$A_{i_4,r}$				
$A_{i_2,r}$	$A_{\text{sc}_{n_i,i}}$		$A_{\text{sc}_{1,i}}$	
$A_{i_3,r}$	$A_{\text{sc}_{1,i}}$		$A_{\text{sc}_{n_i,i}}$	
$P_{z_1,d}(\tau_\text{s})$	≥ 0			
$P_{d,d'}(\tau_\text{s})-1$				
$P_{z_2,d}(\tau_\text{s})$	< 0			
$P_{d,d''}(\tau_\text{s})-1$				
$I_{i_1,r,d}(\tau_\text{s})$	< 0	≥ 0	< 0	≥ 0
$I_{i_4,r,d}(\tau_\text{s})$				
$I_{i_2,r,d}(\tau_\text{s})$	≥ 0			
$I_{i_3,r,d}(\tau_\text{s})$	< 0			

Utilizing the results presented in table 1 and 2, expression (5), the final expression for $\Delta_{\max}(d\tau_\text{s})$ has the following form

$$\begin{gathered}\Delta_{\max}(d\tau_\text{s}) = \max\left|\Delta_\text{set}(d\tau_\text{s})\right| = S(\tau_\text{s},d) + \\ +\left|U_+(\tau_s,d)\delta_+(\tau_s,d) + \left|U_-(\tau_s,d)\right|\delta_-(\tau_s,d)\right|\Phi(\tau_s,d),\end{gathered} \tag{15}$$

where $\delta_\pm(\tau_s,d) = 1\left(\pm\left|U_+(\tau_s,d)\right| \mp \left|U_-(\tau_s,d)\right|\right)$;

$\Phi(\tau_s,d) = 1 - 0.5\delta_+(\tau_s,d)\delta_-(\tau_s,d)$; $1(t)$ is Heavyside function;

$$S(\tau_\text{s},d) = \begin{cases} M_{\max}\left(\sum\limits_{r=1}^{d-1}\left|P_{r,d}(\tau_\text{s})\right| + \left|\left(P_{d,d}(\tau_\text{s})-1\right)\right|\right) + \sum\limits_{i\in N_1} A_{\max_i}\sum\limits_{r=1}^{d}\left|I_{i,r,d}(\tau_\text{s})\right|, \\ \quad \text{if PAM-}n_0\text{-signal is a bipolar signal;} \\ \sum\limits_{i\in N_1} A_{\max_i}\sum\limits_{r=1}^{d}\left|I_{i,r,d}(\tau_\text{s})\right|, \\ \quad \text{if PAM-}n_0\text{-signal is a unipolar signal;} \end{cases}$$

$$U_\pm(\tau_s,d) = \begin{cases} \sum\limits_{j\in N_2}\sum\limits_{r=1}^{d}\left[A_{\text{sc}_{n_j,j}}F_\pm\left(I_{j,r,d}(\tau_s)\right) + A_{\text{sc}_{1,j}}F_\mp\left(I_{j,r,d}(\tau_s)\right)\right], \\ \quad \text{if PAM-}n_0\text{-signal is a bipolar signal;} \\ \sum\limits_{r=1}^{d-1}\left[M_{\text{sc}_{n_0}}F_\pm\left(P_{r,d}(\tau_\text{s})\right) + M_{\text{sc}_1}F_\mp\left(P_{r,d}(\tau_\text{s})\right)\right] + \\ +\left[M_{\text{sc}_{n_0}}F_\pm\left(\left(P_{d,d}(\tau_\text{s})-1\right)\right) + M_{\text{sc}_1}F_\mp\left(\left(P_{d,d}(\tau_\text{s})-1\right)\right)\right] + \\ +\sum\limits_{j\in N_2}\sum\limits_{r=1}^{d}\left[A_{\text{sc}_{n_j,i}}F_\pm\left(I_{j,r,d}(\tau_\text{s})\right) + A_{\text{sc}_{1,j}}F_\mp\left(I_{j,r,d}(\tau_\text{s})\right)\right], \\ \quad \text{if PAM-}n_0\text{-signal is a unipolar signal.} \end{cases}$$

Finaly the equality $\max\left|\Delta_\text{set}\left(dt_{\text{set}_d}\right)\right| = \Delta_\text{pm}$ using the expression (15) takes the form

$$\Delta_\text{pm} = S\left(t_{\text{set}_d},d\right) + \left|U_+\left(t_{\text{set}_d},d\right)\delta_+\left(t_{\text{set}_d},d\right) + \left|U_-\left(t_{\text{set}_d},d\right)\right|\delta_-\left(t_{\text{set}_d},d\right)\right|\Phi\left(t_{\text{set}_d},d\right), \tag{16}$$

where $t_{\text{set}_d} = \left\{\tau_{\text{w.st}_{d,k}}\right\}_{k=1}^{S_\text{w}} \cup \left\{\tau_{\text{w.end}_{d,k}}\right\}_{k=1}^{S_\text{w}}$ is greatest settling time for d-th channel symbol [15, 16].

To obtain the expression for maximum settling error estimation for given time shift at which information about the transmitted channel symbol is retrieved for given symbol duration and number of symbols in information sequence let's analyze the expression for d-th channel symbol settling error $\Delta_\text{set}\left(d\tau'_{\text{s}_d} + t_{\text{sh}_d}\left(\tau'_{\text{s}_d}\right)\right)$ in the absence of AWGN obtained in papers [15, 16], since the structure of considered FSC are the same as in the papers [15, 16]

$$\begin{aligned}&\Delta_\text{set}\left(d\tau'_{\text{s}_d} + t_{\text{sh}_d}\left(\tau'_{\text{s}_d}\right)\right) = \sum_{r=1}^{d-1} M_r P'_{r,d+1}\left(\tau'_{\text{s}_d}, t_{\text{sh}_d}\left(\tau'_{\text{s}_d}\right)\right) + \\ &+M_d\left[P'_{d,d+1}\left(\tau'_{\text{s}_d}, t_{\text{sh}_d}\left(\tau'_{\text{s}_d}\right)\right) - 1\right] + \\ &+M_{d+1}P'_{d+1,d+1}\left(\tau'_{\text{s}_d}, t_{\text{sh}_d}\left(\tau'_{\text{s}_d}\right)\right) + \\ &+\sum_{i=1}^{N}\sum_{r=1}^{d+1} A_{i,r} I'_{i,r,d+1}\left(\tau'_{\text{s}_d}, t_{\text{sh}_d}\left(\tau'_{\text{s}_d}\right)\right),\end{aligned} \quad ,(17)$$

where $P'_{r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)=P'\left(\left[d-r+1\right]\tau'_{\mathrm{s}_d}+t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)$; $I'_{i,r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)=I'_i\left(\left[d-r+1\right]\tau'_{\mathrm{s}_d}+t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)$;

$t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)$ is a time shift relative to the transmission start of the received d^{th} channel symbol in sequence at symbol duration $\tau'_{\mathrm{s}_d}\in\bigcup_{k=1}^{S_{\mathrm{w}}}\left[\tau_{\mathrm{w.st}_{d,k}};\tau_{\mathrm{w.end}_{d,k}}\right]$ [16].

Taking into account the approach for calculation combinations of amplitude values presented in papers [15, 16] let's modify the equality (17) in the following way to obtain the expression for GSE $\left|\Delta_{\mathrm{set}}\left(d\tau'_{\mathrm{s}_d}+t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|$ for considered case:

$$
\begin{aligned}
&\left|\Delta_{\mathrm{set}}\left(d\tau'_{\mathrm{s}_d}+t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|=\\
&\Bigg|\underbrace{\sum_{z_1=1}^{d-1}F_+\left(M_{z_1}P'_{z_1,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)+F_+\left(M_{d'}\left[P'_{d',d'+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)-1\right]\right)+F_+\left(M_{d'+1}P'_{d'+1,d'+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)}_{\left(\hat{C}_+\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\geq 0\right)\vee\hat{C}'_+\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)}+\\
&+\underbrace{\sum_{i_1\in N_1}\sum_{r=1}^{d+1}F_+\left(A_{i_1,r}I'_{i_1,r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)}_{\hat{S}_+\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\geq 0}+\underbrace{\sum_{i_2\in N_2}\sum_{r=1}^{d+1}F_+\left(A_{i_2,r}I'_{i_2,r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)}_{\hat{D}_+\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)}+\\
&+\underbrace{\sum_{i_3\in N_2}\sum_{r=1}^{d+1}F_-\left(A_{i_3,r}I'_{i_3,r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)}_{\hat{D}_-\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)}+\underbrace{\sum_{i_4\in N_1}\sum_{r=1}^{d+1}F_-\left(A_{i_4,r}I'_{i_4,r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)}_{\hat{S}_-\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\leq 0}+\\
&\underbrace{+\sum_{z_2=1}^{d-1}F_-\left(M_{z_2}P'_{z_2,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)+F_-\left(M_{d''}\left[P'_{d'',d''}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)-1\right]\right)+F_-\left(M_{d''+1}P'_{d''+1,d''+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)}_{\left(\hat{C}_-\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\leq 0\right)\vee\hat{C}'_-\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)}\Bigg|
\end{aligned}
\tag{18}
$$

In equality (18) $\hat{C}_+\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)$ and $\hat{C}_-\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)$ are used when PAM-n_0-signal is a bipolar signal otherwise $\hat{C}'_+\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)$ and $\hat{C}'_-\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)$ are used.

It is obvious that the structure of expression (18) repeats the structure of equality (10) therefore expression for $\Delta_{\max}\left(d\tau'_{\mathrm{s}_d}+t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)=\max\left|\Delta_{\mathrm{set}}\left(d\tau'_{\mathrm{s}_d}+t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|$ takes the following forms

$$
\begin{aligned}
&\Delta_{\max}\left(d\tau'_{\mathrm{s}_d}+t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)=\max\left|\Delta_{\mathrm{set}}\left(d\tau'_{\mathrm{s}_d}+t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|=\\
&=S\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)+\left|U'_+\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\delta'_+\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)+\right.\\
&\left.+\left|U'_-\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|\delta'_-\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|\Phi'\left(\tau'_{\mathrm{s}_d},\ {}_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right),
\end{aligned}
\tag{19}
$$

where

$$\delta'_\pm\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)=1\left(\pm\left|U'_+\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|\mp\left|U'_-\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|\right);$$

$$\Phi\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)=1-0.5\delta'_+\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\delta'_-\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)$$

$$
S\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)=\begin{cases}
M_{\max}\left(\sum\limits_{r=1}^{d-1}\left|P'_{r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|+\left|\left(P'_{d,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)-1\right)\right|+\right.\\
\left.+\left|P'_{d+1,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|\right)+\sum\limits_{i\in N_1}A_{\max_i}\sum\limits_{r=1}^{d+1}\left|I'_{i,r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|,\\
\qquad\text{if PAM-}n_0\text{-signal is a bipolar signal;}\\
\sum\limits_{i\in N_1}A_{\max_i}\sum\limits_{r=1}^{d+1}\left|I'_{i,r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|,\\
\qquad\text{if PAM-}n_0\text{-signal is a unipolar signal;}
\end{cases}
$$

and

$$
U'_\pm\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)=\begin{cases}
\sum\limits_{j\in N_2}\sum\limits_{r=1}^{d+1}\left[A_{\mathrm{sc}_{n_j,j}}F_\pm\left(I'_{i,r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)+A_{\mathrm{sc}_{1,j}}F_\mp\left(I'_{i,r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)\right],\\
\qquad\text{if PAM-}n_0\text{-signal is a bipolar signal;}\\
\sum\limits_{r=1}^{d-1}\left[M_{\mathrm{sc}_{n_0}}F_\pm\left(P'_{r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)+M_{\mathrm{sc}_1}F_\mp\left(P'_{r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)\right]+\\
+\left[M_{\mathrm{sc}_{n_0}}F_\pm\left(\left(P'_{d,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)-1\right)\right)+M_{\mathrm{sc}_1}F_\mp\left(\left(P'_{d,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)-1\right)\right)\right]+\\
+\left[M_{\mathrm{sc}_{n_0}}F_\pm\left(P'_{d+1,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)+M_{\mathrm{sc}_1}F_\mp\left(P'_{d+1,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)\right]+\\
+\sum\limits_{j\in N_2}\sum\limits_{r=1}^{d+1}\left[A_{\mathrm{sc}_{n_j,i}}F_\pm\left(I'_{j,r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)+A_{\mathrm{sc}_{1,j}}F_\mp\left(I'_{j,r,d+1}\left(\tau'_{\mathrm{s}_d},t_{\mathrm{sh}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)\right)\right],\\
\qquad\text{if PAM-}n_0\text{-signal is a unipolar signal;}
\end{cases}
$$

Taking into account expression (19), the results of papers [15, 16] the equation $\Delta_{\max}\left(d\tau'_{\mathrm{s}_d}+t_{\mathrm{sh.pm}_d}\left(\tau'_{\mathrm{s}_d}\right)\right)=\Delta_{\mathrm{pm}}$ for permissible time shift $t_{\mathrm{sh.pm}_d}\left(\tau'_{\mathrm{s}_d}\right)$, given values of permissible error Δ_{pm}, symbol duration τ'_{s_d} and d-th symbol in information sequence at the output FSC can be formulate in the following way, according [16]

$$t_{\mathrm{sh.pm}_d}\left(\tau'_{\mathrm{s}_d}\right)=\min T_{\mathrm{sh}}\left(\tau'_{\mathrm{s}_d}\right),\tag{20}$$

where $T_{\mathrm{sh}}\left(\tau'_{\mathrm{s}_d}\right)$ is the solution of the following equality

$$
\begin{aligned}
&S\left(\tau'_{\mathrm{s}_d},T_{\mathrm{sh}}\left(\tau'_{\mathrm{s}_d}\right)\right)+\left|U'_+\left(\tau'_{\mathrm{s}_d},T_{\mathrm{sh}}\left(\tau'_{\mathrm{s}_d}\right)\right)\delta'_+\left(\tau'_{\mathrm{s}_d},T_{\mathrm{sh}}\left(\tau'_{\mathrm{s}_d}\right)\right)+\right.\\
&\left.+\left|U'_-\left(\tau'_{\mathrm{s}_d},T_{\mathrm{sh}}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|\delta'_-\left(\tau'_{\mathrm{s}_d},T_{\mathrm{sh}}\left(\tau'_{\mathrm{s}_d}\right)\right)\right|\Phi'\left(\tau'_{\mathrm{s}_d},T_{\mathrm{sh}}\left(\tau'_{\mathrm{s}_d}\right)\right)=\Delta_{\mathrm{pm}}\ .
\end{aligned}
\tag{21}
$$

Taking into account the results of papers [15,16], the dependence of effective memory for considered math model on CSD takes the form

$$
\begin{aligned}
\hat{G}\left(\tau_{\mathrm{s}}\right)=\min\Bigg\{&G'\left(\tau_{\mathrm{s}}\right):0<R_h+\sum_{j_1=1}^{h}\left[\left|P_{l-j_1+1,l}\left(\tau_{\mathrm{s}}\right)\right|+\sum_{i=1}^{N}\frac{A_{\max_i}}{M_{\max}}\left|I_{i,l-j_1+1,l}\left(\tau_{\mathrm{s}}\right)\right|\right]-\\
&-\sum_{j_1=1}^{G'\left(\tau_{\mathrm{s}}\right)+1}\left[\left|P_{G'\left(\tau_{\mathrm{s}}\right)-j_1+2,G'\left(\tau_{\mathrm{s}}\right)+1}\left(\tau_{\mathrm{s}}\right)\right|+\sum_{i=1}^{N}\frac{A_{\max_i}}{M_{\max}}\left|I_{i,G'\left(\tau_{\mathrm{s}}\right)-j_1+2,G'\left(\tau_{\mathrm{s}}\right)+1}\left(\tau_{\mathrm{s}}\right)\right|\right]\leq\varepsilon\Bigg\}.
\end{aligned}
$$

Here R_h is h^{th} remainder of the majorizing series; ε is a parameter dependence on accuracy of resolution time estimation $\varepsilon_{\mathrm{res}}$.

Based on results obtained above in this paper and the results presented in papers [15, 16] the algorithm implementation for main system parameters estimation for considered FSC presented in Fig. 2-5 and algorithm implementation subroutine for estimating the parameters of majorizing series (E_H and $\tilde{\tau}_s^{(H)}$) presented in Fig. 6.

In Fig. 2-5 under := we understand the operation of variable or function definition

In Fig. 2 under type and configuration of *j*-th of PAM-n- signal we are understood as: the number of discrete states n_j, the type of SC (unipolar or biopolar signal type), the values of ΔM_{st} or ΔA_{st_i}, M_{sh} or A_{sh_i}.

In Fig. 3 under W_{-1}(.) we understand Lambert W function when branch -1 is used.

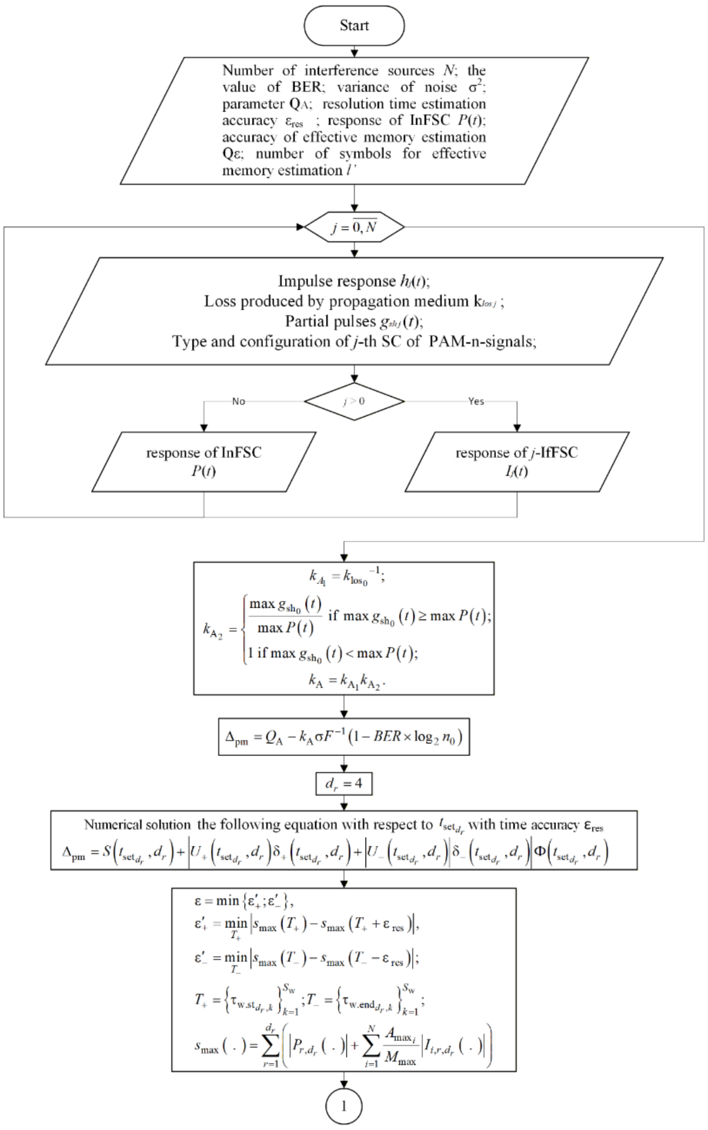

Fig. 2. The first section of algorithm implementation of main system parameters estimation for considered FSC

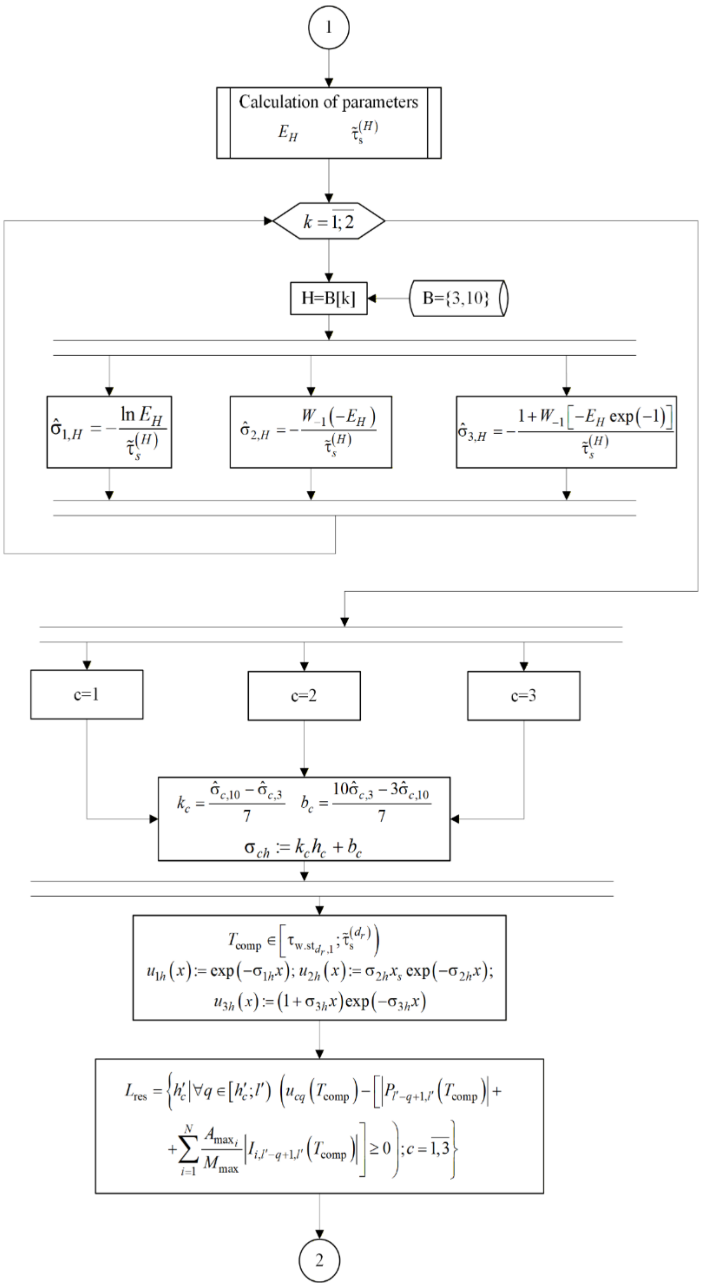

Fig. 3. The second section of algorithm implementation of main system parameters estimation for considered FSC

In Fig. 4 under $\lceil . \rceil$ we understand ceil function; δ_{qc} is Kronecker delta

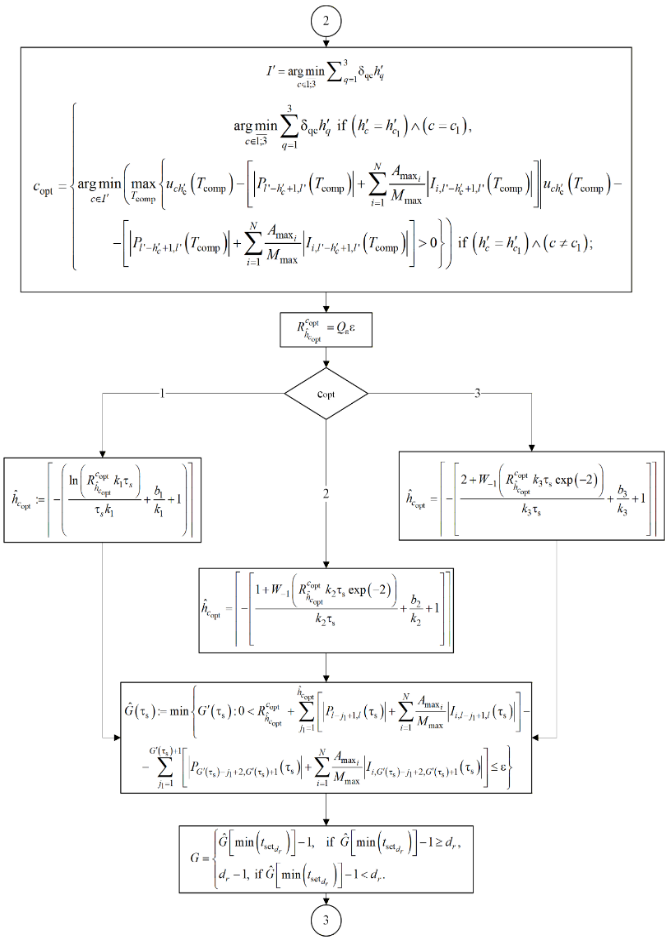

Fig. 4. The third section of algorithm implementation of main system parameters estimation for considered FSC

In Fig. 5 the following designations are used [16]: $T_{\text{sh.pm}}$ is permissible time shift; ΔT_{opt} and ΔT_{opt_d} are optimal time shift for retrieving information about d^{th} channel symbol within $d \geq G+1$ and $d < G+1$, respectively at which minimum GSE is achieved while $\tau_{\text{s}} = \tau_{\text{w.st}_1}$; δ_{spr} is the largest spread of optimal time shifts for retrieving information; SA is the attenuation for information signal at the output of the InFSC caused by the incomplete amplitude settling of the partial signal pulse; $C_{\text{lb}}(n_0)$ is lower bound capacity estimation; $C_{\text{alb}}(n_0)$ is auxiliary lower bound capacity estimation.

In Fig. 6 under Min SNR and Min $SNR(p)$ we understand minimum required signal-to-noise ratio in the absence / in the presence of the maximum feducial symbol sampler instability p for given BER, see expressions for them presented in papers [15, 16]. On practice for the considered algorithm $l' \leq 30$.

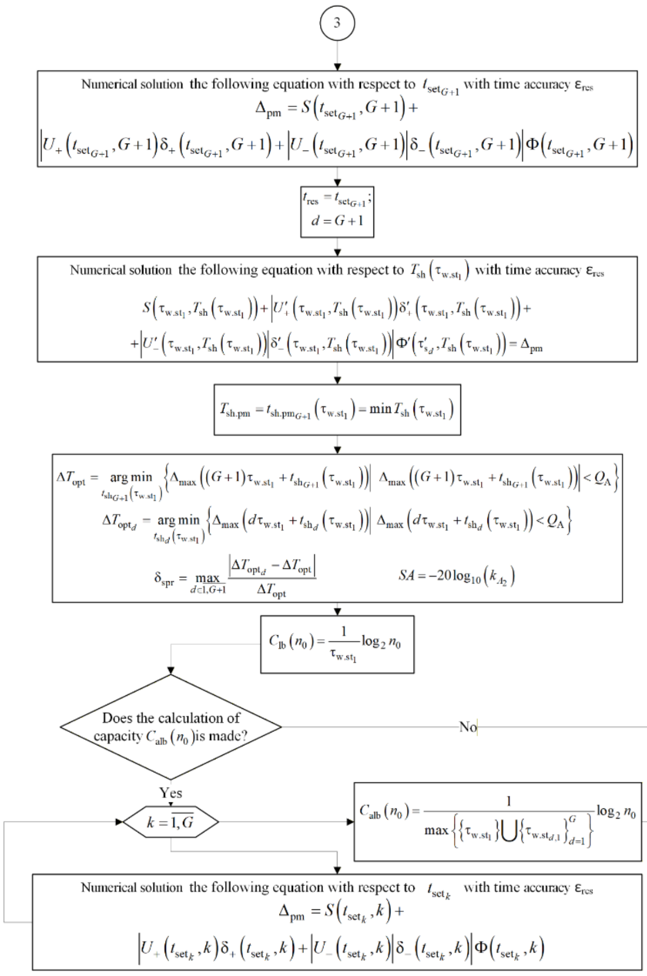

Fig. 5. The fourth section of algorithm implementation of main system parameters estimation for considered FSC

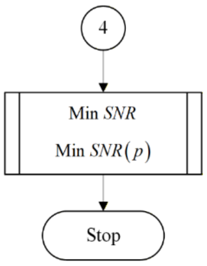

Fig. 6. The fifth section of algorithm implementation of main system parameters estimation for considered FSC

Conclusion

A new phenomenological method and algorithm implementation for estimating the system parameters of a composite communication channel with memory are developed in the paper for major case of composite frequency selective channel while both types of PAM-n-signals are used.

The channel considered in the paper consists of frequency selective information channel while a multi-position amplitude-pulse signal is transmitting, which can be either unipolar or bipolar, as well as signals transmitted through interfering frequency selective channels. A distinctive feature of the developed method and algorithm implementation is that, firstly, they have polynomial complexity, which is independent of the size of the channel alphabets of the multi-position amplitude-pulse signals. The obtained method and algorithm implementation have the following restriction: the start time of transmission of each signal and transmission rate are the same.

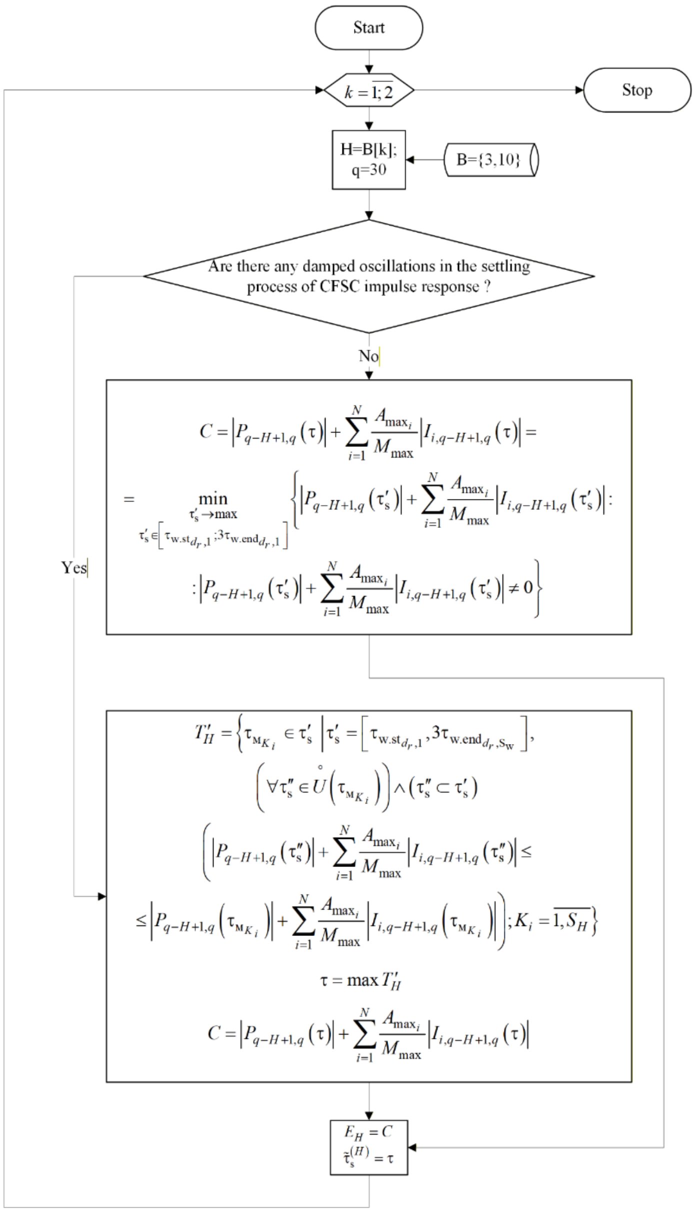

Fig. 7. Algorithm implementation subroutine for estimating the parameters of majorizing series

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АЛГОРИТМ ОЦЕНКИ ОСНОВНЫХ СИСТЕМНЫХ ПАРАМЕТРОВ СОСТАВНОГО ЧАСТОТНО-СЕЛЕКТИВНОГО КАНАЛА, ИСПОЛЬЗУЮЩЕГО РАЗЛИЧНЫЕ ТИПЫ СИГНАЛОВ АИМ-N-СИГНАЛОВ ПРИ НАЛИЧИИ ПЕРЕКРЕСТНЫХ ПОМЕХ

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Аннотация

В статье разработаны новый феноменологический метод и алгоритм оценки системных параметров составного канала связи с памятью (пропускная способность при заданном значении частоты битовых ошибок, требуемое отношение сигнал/шум для реализации и т.д.). Рассматриваемый в статье канал связи состоит из частотно-избирательного информационного канала, в котором передается многопозиционный амплитудно-импульсный сигнал, который может быть как однополярным, так и двухполярным, мешающие частотно-избирательные каналы по которым также передаются подобные сигналы. Полученные метод и реализующий его алгоритм для общего случая реализации частотно-селективного канала являются развитием ранее полученных результатов в рамках теории времени разрешения для широкополосных каналов связи. Результаты могут также представлять интерес и для специалистов, разрабатывающих системы связи на транспорте в автомобильной и авиационных отраслях, а также в системах широкополосной проводной передачи данных. Отличительной особенностью разработанного метода и реализующего его алгоритма является, во-первых, их полиномиальная сложность, не зависящая от размера канальных алфавитов многопозиционных амплитудно-импульсных сигналов. Полученный метод и алгоритм имеют следующее ограничение: время начала передачи каждого сигнала и скорость передачи одинаковы.

Ключевые слова: *МСИ, разрешающее время, пропускная способность, теория разрешающего времени, АИМ-n-сигналы, алгоритм с линейной вычислительной сложностью, перекрёстные помехи*

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