A STUDY OF NOISE IMMUNITY OF MULTICHANNEL RADIO CIRCUIT WITH A BAND-SAVING MODULATION METHOD UNDER THE INFLUENCE OF NOISE FROM NEIGHBOURING CHANNEL

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Abstract

In this paper, we present the results of investigation of influence of Interchannel Interference (ICI) on the merit of the reception of different coherent multichannel digital radio systems, used band-saving modulation methods. We show that the estimation of merit of the reception depends on power of ICI, as well as it depends on timing shifts and phase shifts of ICI relative to useful signal. In addition, in general, that's true to take into account as the influence of near-by ICI channels, as the influence of distant ICI channels. In paper we present the results of comparisons of the merit of reception in the presence of influence of ICI and Gaussian noise for band-saving modulation methods and systems.

1. Introduction

Quadrature phase shift keying (QPSK)[1], minimum shift keying (MSK)[2], tamed frequency modulation (TFM)[3] are the band-saving modulation methods. These methods are efficient for application in multichannel coherent digital satellite data transmission (DT) radio systems [3,4]. QPSK signal has been examined for application in multichannel coherent digital television (TV) radio systems[5].

Symbol error probability is the performance of efficiency for digital DT systems. For TV systems merit of received images is determined with help of visional evaluation. In multichannel digital radio systems, in general, adjacent channel signal is different from useful signal by amplitude (U), carrier frequency shift (df), informative symbols sequence, symbol timing shift (dt) and carrier phase shift (dF). For useful signal the adjacent channel signal is ICI. We can assume that symbol's duration of ICI is a little relative to duration of communication time interval, and in addition, U and df are fixed. These is the case of nonfading reception in practice.

Then, if ICI from everybody interfering channels and white Gaussian noise act, symbol error probability (P) is evaluated as the average over all random sequences of interference symbols. However, P depends on dt and dF, i.e. $P=P(\overline{dt},\overline{dF})$ (lengths of $\overline{dt},\overline{dF}$ vectors are determined by the number acting interfering channels). The actual questions appear:

A. How much does P depends on shifts influence ?

B. What cases and systems do we must consider the shifts influence in ?

C. What cases do we can take the average over $(\overline{dt},\overline{dF})$ in ?

There are several papers [1],[6]-[8] wich are regarded the problem of P avaluating in the presence of the influence of ICI and Gaussian noise.

For example, in [6] there were deriving expressions for worst case of carrier phase shift in MSK systems, but influence of random ICI symbols and influence of symbol timing shifts were not taken into account.

In other analysis [7] there were represented average estimations over all shifts in MSK systems. An aquivalent white Gaussian noise model for ICI is used in [1] for to estimate perfomance degradation because of ICI influence in binary phase shift keying (BPSK), QPSK systems.

An analogous model of ICI is emploied in order to investigate MSK, TFM systems in [8].

In these and others published researchs there were not found the answers on acked questions above. In addition, all published results taken into account the influence of only near-by interference channels (two channels influence). The problem of image merit estimation in the presence of the influence of ICI and the question of band-saving MSK, TFM methods application in TV systems are little studied today too.

In our investigation, we create theoretical techniques and *sufficiently convenience design means of simulating in order* to estimate ICI influence on reception merit in multichannel coherent digital DT and TV systems of different modulation methods, even if synchronization errors and intersymbol interference (ISI) are presence.

In this paper, we present as the timing shifts (dt) and phase shifts (dF) influences results on P, as interfering acting channels number influence results on P for coherent multichannel digital DT and TV systems with BPSK, QPSK, MSK, TFM modulation methods application. Channel optimization techniques and result are shown too in paper. We publish the results of ICI and Gaussian noise influence comparison in different systems for several type cases.

2. The choice of criterion

In concrete communication interval, the P depends on stability of channel symbol and carrier freqvency oscillators, as well as the P depends on communication interval duration (CID) [10].

In the case of high stability of oscillators and little CID, we can consider that dt and dF are fixed. Then P depends on random fixed shifts. Since, in independent cannels the values of shifts are not known, that's true to estimate P for most dangerous shifts. Then the best modulation method (B) is determined (on j=1..J *multitude of all modulation methods*) by *MINIMAX criterion* as

$$B = \underset{j}{\mathrm{MIN}}\ \underset{(\overline{dt},\overline{dF})}{\mathrm{MAX}}\ P_j(\overline{dt},\overline{dF}) \qquad (1)$$

In the case of low stability of oscillators and large CID, the communication merit is estimated by average P. Then the best modulation method is determined by AVERAGE criterion as

$$B = \underset{j}{\mathrm{MIN}} \langle P_j \rangle \tag{2}$$

3. The descriptions of investigated sygnals and systems

We examine QPSK, MSK, TFM band-saving modulation methods in this work, and BPSK [1] traditional modulation method is included for comparison.

Basic modulation methods analitical expressions are represented as [1]-[3]

BPSK: $$U_s(t) = U_s I_s(t) \cos(2\pi f_s t + F_s) \tag{3}$$

QPSK: $$U_s(t) = (U_s/\sqrt{2}) I_{s,s}(t) \sin(2\pi f_s t + \pi/4 + F_s) + (U_s/\sqrt{2}) I_{s,c}(t) \cos(2\pi f_s t + \pi/4 + F_s) \tag{4}$$

MSK: $$U_s(t) = U_s \cos\left(2\pi f_s t + (\pi/2)\left(I_s(t)\tau_s/T_s + \sum_{m=1}^{N-1} I_{s,m}\right) + F_s\right), \text{ for } N\text{-symbol} \tag{5}$$

TFM: $$U_s(t) = U_s \cos\left(2\pi f_s t + \pi \int_0^t \sum_{m=-\infty}^{\infty} I_{s,m}\, g(\tau - m T_s)\, d\tau + F_s\right) \tag{6}$$

Where : Us ,fs ,Fs denote, according to, the amplitude, carrier frequency, initial phase of signal; Is,m, Is(t) the informative symbols sequence of Ts duration; Is,c(t), Is,s(t) is the informative symbols sequence of 2Ts duration, according to, for different quadrature channels; τ_s is the time variable, and $0 < \tau_s < T_s$; g(t) denotes TFM premodulation impulse response.

In our work, we use TFM premodulation filter response with 7-symbols lenth truncation [3].

Informative symbols are ±1 with 0,5 probability. The analitical expressions of ICI accord (3)-(6) expressions of signals, but all represented variables of according ICI have 'i' index instead signal 's' index. In different from BPSK, the QPSK, MSK, TFM methods are quadrature methods. Fig. 1 represents the coherent reception part structure scheme of one quadrature channel. This scheme consists of according optimum (in the presence of white Gaussian noise only) coherent demodulator, decision device (DD) and decoding relative device (differential decoder). We will call this reception structure as basic reception channel. In addition, if transmitter das not distort basic modulation method spectrum (there are not narrow-band filters in sending side), then we will call this channel as basic channel.

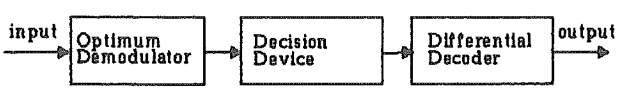

Figure 1. Coherent reception structure of basic channel

In this work, we examine as basic channels of different modulation methods, as basic channels with addition of different receiver's filters and transmitter's filters (rectangular filters, Nyquist filters etc).

4. Theoretical techniques of investigation

The theoretical investigation [9,10] is released in order to estimate P in influence of ICI and Gaussian noise in systems with absence of ISI. This systems are BPSK, QPSK, MSK basic channels.

Let in the input of basic reception channel there is the mixture of n-realization of useful signal Uin,s,n(t), l-realization of ICI of everybody acting channels Uin,i,l(t), white Gaussian noise N(t) .

Then input voltage is represened as

$$U_{in}(t) = U_{in,s,n}(t) + U_{in,i,l}(t) + N(t) \tag{7}$$

Let we consider that optimum demodulator is lineal and synchronization is ideal.

Then conditional error probability of useful k-symbol is estimated as [10]

$$P_K = 1 - \Phi\left[\frac{M_{s,n}(t) + M_{i,l}(t)}{\sqrt{D}}\right] \tag{8}$$

where : Ms,n(t), Mi,l(t) denote, accoding to, voltage of n-realization of useful signal and voltage of l-realization of sum ICI of everybody acting channels in the input of DD at the t counter time moment; D is dispersion of Gaussian noise in DD input,

Φ denotes probability integral, $\Phi = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} \exp(-t^2/2)\, dt$.

If ISI is absence, then in basic channels $|M_{s,n}(t)| = M_o$ for any n.

Then we can decompose the expression (8) in the line of Teilor for $\frac{M_o}{\sqrt{D}}$ point on $\frac{M_{i,l}}{\sqrt{D}}$ degrees, and we can write [9,10]

$$P_K = 1 - \Phi(\eta) + K_1[M_{i,l}(t)] + \ldots + K_n[M_{i,l}(t)]^n$$
$$K_n = (1/n!)(\eta/M_o)^n\, d^n\Phi/dx^n \big|_{x=\eta} \tag{9}$$

where $\eta = \frac{M_o}{\sqrt{D}}$. If we average the expression (9) over everybody combinations of ICI symbols at the demodulation's time interval, and after we take into account that odd degrees members of line equal zero, then we obtain the estimation [10]

$$P = 1 - \Phi(\eta) + \sum_{c=2}^{\infty} K_c \overline{[M_i(t)]^c}, \quad c \text{ is even} \tag{10}$$

Necessary number of members of line (10) is determined by required exactitude of P estimation, as well as by parameter

$$\lambda = \eta^2 \sqrt{\frac{\overline{[M_i(t)]^2}}{M_o^2}} \tag{11}$$

For example, if required exactitude of P estimation is 30% and $\lambda < 1$, then $\overline{[M_i(t)]^2}$ second moment of ICI is sufficient for estimation.

In described systems, we find the estimations of $\overline{[M_i(t)]^c}$ as $\overline{[M_i(t)]^c} = F_c(\overline{dt}, \overline{df})$ (F_c is some function), that allows to obtain as minimax criterion estimations of P, as average criterion estimations of P for different modulation methods.

In addition, by means of these theoretical techniques we investigate the influence of number of taken into account acting ICI channels on estimation of P for different modulation methods.

5. The results of theoretical investigation

Table 1 represents the results of theoretical investigation for next conditions: symbol energy ratio Eb/No=10 db (Eb is the energy per bit, No is white Gaussian noise spectral density), frequency shift between channels relative to symbol frequency (1/ Ts) df=1,6 , input interference to signal ratio (Ui/Us)=0 db, and informative rates of everybody channels are equal. Next conclusions follow from obtained results. P is increased because of ICI influence. Value of P depends on power of ICI, as well as it depends on timing shifts and phase shifts of ICI relative to useful signal. Therefore, that's true to consider the P estimation by average criterion (average P) and by minimax criterion (worst case).

Modulation method	Namber of accounted channels of ICI	Criterion Average	MINIMAX
BPSK	6	$8,6\ 10^{-4}$	$5,0\ 10^{-3}$
	2	$3,0\ 10^{-4}$	$5,0\ 10^{-4}$
QPSK	6	$3,0\ 10^{-4}$	$7,0\ 10^{-4}$
	2	$1,6\ 10^{-4}$	$3,4\ 10^{-4}$
MSK	6	$1,0\ 10^{-5}$	$1,5\ 10^{-5}$
	2	$0,8\ 10^{-5}$	$1,1\ 10^{-5}$
TFM	6	$1,0\ 10^{-4}$	$1,0\ 10^{-4}$
	2	$1,0\ 10^{-4}$	$1,0\ 10^{-4}$

Table 1. Estimations of symbol error probability (P) in the case of Eb/No=10 db, df=1,6 , (Ui/Us)=0 db.

In general, P depends on influence of near-by channels (on frequency), as well as it depends on influence of distant channels. Moreover, if influence of distant channels is not taken into account in P estimation, then it can lead to significant errors in P estimation in some cases (see table 1).

The number of channels of ICI taken into account in P estimation depends on filtrating properties of receiver, as well as it depends on modulation method.

For example, in basic channels of BPSK, QPSK modulation methods, it is required to take into account in P estimation the influence of not less than 6 channels of ICI. In MSK, TFM systems influence of shifts and number of ICIchannels on P is significant smaller.

From the released investigation it follows, that in general, the information about energy spectrum of ICI is not sufficient in order to estimate P. It is significant to take into account as power of ICI, as timing structure and statistical properties of ICI. Only in the case of: large noise (Eb/No<3db), df=1,6 , (Ui/ Us)=0 db , P estimation obtained with help of energy spectrum is true by average criterion exepctionly.

In addition, by means of theoretical methods with help of obtained $\boxed{Mi(t)}$ moments of ICI, the coefficient of excess of DD input mixture of ICI and Gaussian noise was investigated. In result, conclusion was released that's true by means of Gaussian noise model (1,8) to take into account the influence of distant channels of ICI (for example, beginning with 7 channel in BPSK, QPSK systems), since in this case the DD input mixture (for distant ICI channels) is practically Gaussian. However, in general, with considering of influence of near-by ICI channels, the DD input mixture is not Gaussian. Consequently, the influense of near-by channels of ICI is not true to take into account by means of Gaussian noise model, and it is requered to determine this influence according to expression (8).

6. The account-and-simulation model

Discribed above theoretical methods are sufficient in order to investigate simple systems, such as basic channels. However, the investigation of more complex systems with addition of different filters is difficult or it requeres the significant admissions.

So, the account-and-simulation model (ASM) was created in (12). The ASM is basic on the combination of statistical experiment and account. Advantage of this ASM is high time action. In the result of original method of determination of P , the time interval of statictical experiment is decreased more than in 10 time relative to usual simulation model on $P<10^{-4}$

The ASM, at not long time interval, for high immunity systems, in presense of the influence of ICI and Gaussian noise, allows to investigate different modulation methods and channel structures, to create the optimization of parameters of channel structures, to estimate the influence of synchronization errors on reception merit. In ASM the acting ICI channels are simulated with took into account of timing shifts and phase shifts relative to useful signal, that allows to obtain the minimax criterion and average criterion estimations.

We created the investigations (12) of verification of adequcy and statistical reliability of ASM results. In order to verify the adequcy of ASM, the ASM results were compared with theoretical reliable results, obtained with absence of significant admissions in used theoretical method. In addition, we compared the ASM results with analogous results of usual simulation model on $P<10^{-4}$

In order to verify the statistical reliability of ASM results, we obtained the line of quantities of selected P and we examined the statistical distribution of this line. The results of examination follow to consider that mean-square error of obtained ASM estimations not exeeds the 30% from P for taken selection of statistical experiment. In the result of described investigations we created the conclusion that ASM is adequcy and ASM results are statistical reliable.

By means of ASM we investigated BPSK, QPSK, MSK, TFM modulation methods and systems (12). Investigated coherent channel structure of these systems consists of the according basic channel (fig. 1) or basic channel with addition different receiver's filters and transmitter's filters. For example, one of the class of the investigated channels, is class of channels with rectangular receiver's filter with bandwidth taken as optimum bandwidth by criterion of minimum of P. The optimum bandwidth was found by means of approached theoretical methods and by means of ASM.

For high immunity systems worked in the conditions of little level of noise (Eb/No>10 db), approached estimation (A) of optimum bandwidth of receiver's filter, for taken into account the influence from H acting ICI cannels, is determined by numeral solving of equation (11)

$$\sum_{i=1}^{H}(U_i/U_s)^2\left[G_s(A/2+2\pi(f_i-f_s))+G_s(A/2-2\pi(f_i-f_s))\right]-G_s(A/2)=0 \quad (11)$$

Where Gs(f) denotes the energy spectrum of received signal.

If the shape of frequency performance of transmitter's filter is Wt(f), and if the energy spectrum of according basic modulation method is Sb(t), then Gs(f) is determined as

$$G_s(f)=Wt(f)\ Sb(t) \quad (12)$$

In addition, by means of ASM we investigated the channels with Nyquist filters too.

7. The results of asm investigations

In the results of ASM investigations (12), we obtained the dependency of energy loss (L) (relative to ideal BPSK basic channel in presence of Gaussian noise only) from df in case of conditions: $P=10^{-4}$;(Ui/Us)=0 db (see fig. 2) by minimax criterion, and $P=10^{-4}$; (Ui/Us)=20..40 db (see fig. 3) by average criterion. In represented cases informative rates of channels are equal, and synchronization is ideal. (Influence of synchronization errors is investigated separately.) In the base of obtained results we create following conclusions.

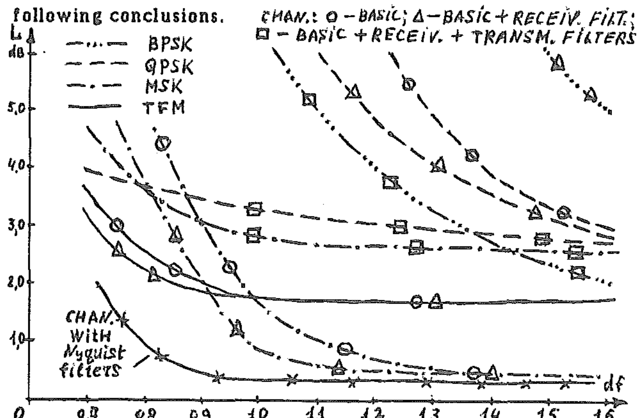

Figure 2. Graphic of dependency of energy loss (L) from frequency shift (df) in the case of $P=10^{-4}$,(Ui/Us)=0 db by minimax criterion.

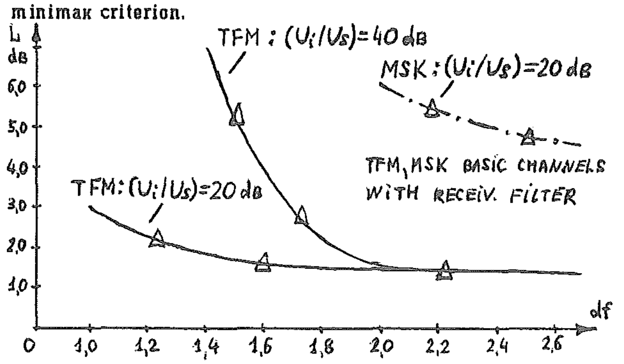

Figure 3. Graphic of dependency of energy loss (L) from frequency shift (df) in the case of $P=10^{-4}$,(Ui/Us)=20..40 db by average criterion.

In the case of (Ui/Us)=0 db, the most frequency efficiency (relative to others represented channels) is provided by means of the Nyquist channel application. This channel in the case of df=0,7 has L=2,0 db (see fig. 2).

The modulation method TFM provides the most frequency efficiency (with compare to others represented modulation methods). TFM in the case of (Ui/Us)=0 db and df=0,7 has L=3,4 db (see fig. 2), and in the case of (Ui/Us)=20 db and df=1,0 has L=3,0 db (see fig. 3).

In the case of (Ui/Us)=0 db and df>1,0 , the MSK is more relative to efficient, as MSK is more simple method in order to realize the coherent reception relative to TFM method. In this case by means of MSK we can obtain L<0,8 db (see fig. 2).

Results of investigation of synchronization errors influence on reception merit show that in the presence of ICI and Gaussian noise the errors of carrier phase synchronization are fewer influence in the case of large level of noise (Eb/No<3 db) for BPSK systems, but in the case of little level of noise (Eb/No>10 db) for MSK systems (relative to others systems with equal parameters of systems :level of ICI, df etc).

8. The results of investigations of tv systems

With help of investigations of TV systems by means of created simulation TV model, we determine the ratio between the subjective (visional) and objective (word error probability Pw) estimations of merit of image, that allows to use the results of above represented investigation of digital DD systems in order to estimate the influence of ICI and Gaussian noise on the merit of received images in coherent multichannel TV systems, but with account of this ratio. For example, in the result of the TV simulation we obtain that in the presence of influence of ICI and Gaussian noise the 'good' quality of visional estimation of merit of received images accords the $Pw<10^{-2}$(in the case of basic fixed parameters of origin transmitter images). We obtain that the application of MSK, TFM band-saving modulation methods provides the best quality received images (relative to application of BPSK, QPSK modulation methods) in the case of large level of influence of ICI ((Ui/Us)>0 db) and little level of noise (Eb/No>10 db).

In addition to written above, we want to say that our investigations in some other way (14) show that significant improvement of merit of received images is connected with took into account the properties and particulars of subjective visional system. In this system the intellectual sensory receiver of visional information is appeared. This way leads to creating the intellectual systems possessing the properties of artificial intellect. We were a success to create new original conception of building of intellectual receiver basing on the combination of the biological and informatically-technical principles. In result, we create the structure scheme of visional system allowing to improve the merit of receiverd images by means of the following optimization of channel parameters (14).

9. Conclusion

The results of investigation show that the application of QPSK, MSK, TFM band-saving modulation methods in coherent

BPSK :

QPSK :

MSK :

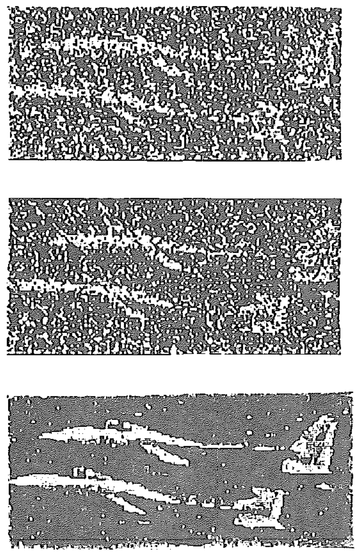

Figure 4. Received images for basic channels for case of: $E_s/N_0 = 7\,dB$, $V_i/V_s = 12\,dB$, $df = 3,0$.

BPSK :

QPSK :

MSK :

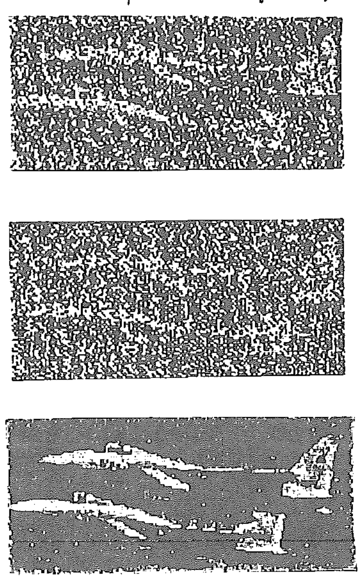

Figure 5. Received images for basic channels for case of: $E_s/N_0 = 10\,dB$, $V_i/V_s = 15,6\,dB$, $df = 3,0$.

BPSK :

QPSK :

MSK :

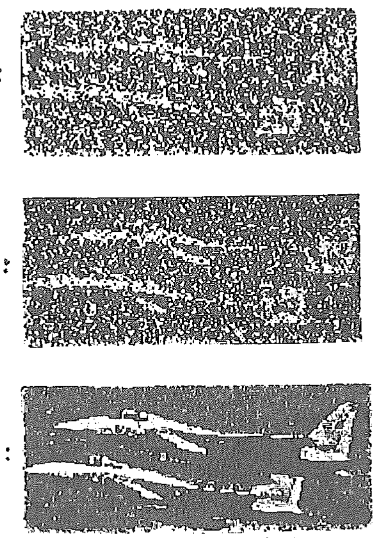

Figure 6. Received images for basic channels for case of: $E_s/N_0 = 10\,dB$, $V_i/V_s = 12\,dB$, $df = 1,0$.

BPSK :

QPSK :

MSK :

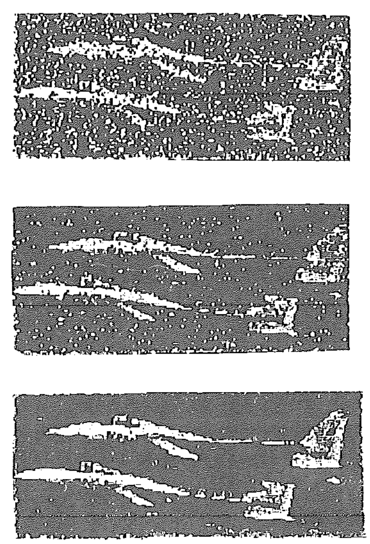

Figure 7. Received images for basic channels for case of: $E_s/N_0 = 10\,dB$, $V_i/V_s = 6\,dB$, $df = 1,0$.

multichannel digital DD and TV systems is more efficient than the application of BPSK traditional modulation method, especially in the case of large level of ICI (df<1,0 and (Ui/Us))0 db) and little level of noise (Es/No>10 db).

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