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Investigation of Characteristics of Quadrative - Amplitude Modulation Affecting Interference-Resistant Reception

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ABSTRACT

The article analyzes the main reasons for reducing reliability, channel violations during the transmission and reception of digital television signals. The main regularities of noise-resistant formation of quadrature-amplitude modulation are investigated. Mathematical models, vector diagrams of the QAM signal and the results of a theoretical study of the dependence of the bit error probability on E_b/N_0, to ensure noise-immune reception of digital television signals.

KEYWORDS: Quadrature Amplitude Modulation, vector signal, carrier frequency generator, digital-to-analog converter, biphasic signal, Bit Error Rate (BER), Signal to Noise, SNR-Signal Noise Ratio.

Normalized S/N version for digital communication channels

The purpose of any communication channel is the transmission of this or that information. In this case, we consider broadband communication channels designed to transmit both video and audio signals. It is known from communication theory that there are two main reasons for the decrease in transmission reliability [1].

The main reason for this is a decrease in the signal-to-noise ratio (S/N-Signal to Noise or SNR-Signal Noise Ratio) and the next reason is signal distortion due to various interferences.

Channel disturbances simulate various real-world problems, including additive white Gaussian noise (AWGN), phase noise (also called jitter), fading, multi-tone interference, and quadrature inaccuracies. Standard visualization tools such as constellation plots, eye diagrams, and trellis diagrams are available, as well as standard measurements for bit error rate (BER), quadrature disturbances, packetization time, and modulation quality. Channel coding is supported with linear block codes and convolutional codes, as well as direct sequence spread spectrum (DSSS). Channel equalization is available for intersymbol interference (ISI) correction [2].

Quadrature Amplitude Modulation (QAM), QAM is a signal in which two carriers 90 degrees out of phase are modulated and the resulting output consists of amplitude and phase changes. Due to the fact that both amplitude and phase changes are present, it can also be considered as a mixture of amplitude and phase modulation [2].

This type of modulation is a mixture of two types of modulation: amplitude and phase modulation. In this case, the QAM (QAM) modulated signal consists of the sum of two orthogonal carriers: cos and sin components, which have different digital values, below is a mathematical model of this QAM modulated signal:

$$U_{QAM}(t) = U_c(I(t)\cos\omega_c t + Q(t)\sin\omega_c t) = U_c(I(t)\cos(2\pi f_c t) + Q(t)\sin(2\pi f_c t) \quad (1)$$

where: I(t), Q(t)-modulating signals, f_c – carrier frequency

Based on expression (1) for QAM-16, we can write the following mathematical model (2)

$$U_{QAM-16}(t) = \sum_{i=1}^{16} A_i\,(\cos(\omega_c t + Q_i) \quad (2)$$

Quadrature amplitude modulation QAM used for digital transmission for radio applications is capable of carrying higher data rates than conventional amplitude modulation and phase modulation schemes. As with phase keying, etc. The number of points on which a signal can be built, i.e. the number of points in the constellation, indicated in the description of the modulation format, for example. 16-QAM uses a 16-point constellation [2].

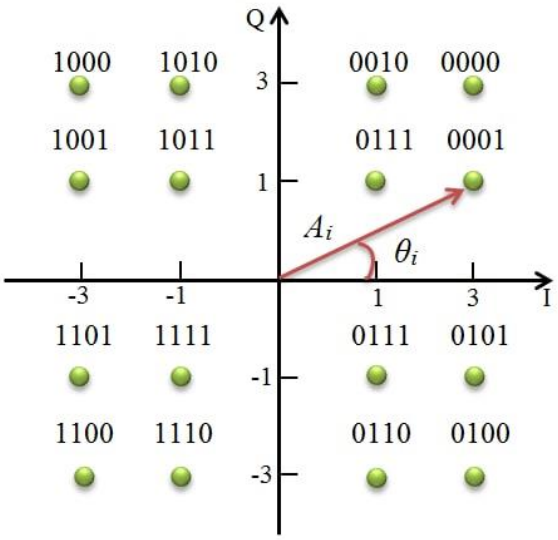

Fig.1. Vector signal diagram for QAM-16.

In Fig.1. a vector diagram of the signal for KAM-16 is presented. Using a vector diagram, you can represent a modulated QAM-16 signal by decomposing it into in-phase (I) and quadrature (Q) components.

Using the trigonometric formula, you can get the following expression:

$$\cos(x+y) = \cos x \cos y - \sin x \sin y \quad (3)$$

From expression (3), the mathematical model of the modulated signal has the following form:

$$x(t) = A_i(t)\cos\theta_i(t)\cos(2\pi f_c t) + A_i(t)\sin\theta_i(t)\sin(2\pi f_c t) \quad (4)$$

Introducing the in-phase and quadrature components into (4), we obtain the following expression:

$$x(t) = I(t)\cos(2\pi f_{\text{н}} t) + Q(t)\sin(2\pi f_{\text{н}} t) \quad (5)$$

where: $I(t) = A_i(t)\, cos\, \theta_i(t)$

$Q(t) = A_i(t)\sin\theta_i(t)$

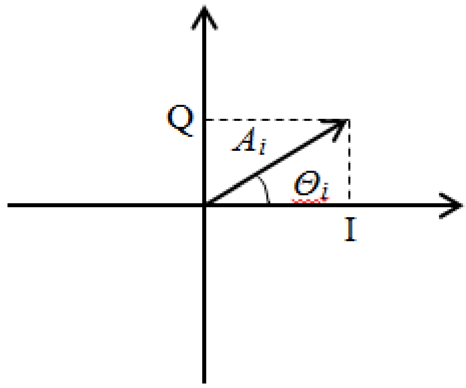

Fig.2. Vector diagram showing amplitude and phase QAM signal.

Figure 2 shows a vector diagram showing the amplitude and phase of the QAM signal. In this case, the in-phase components (I) are plotted horizontally, the quadrature components (Q) are plotted vertically.

The relationship between components (I) and (Q) is expressed as follows:

$$A_i(t) = \sqrt{I^2(t) + Q^2(t)} \quad (6)$$

$$\theta_i(t) = tg^{-1}\frac{Q(t)}{I(t)} \quad (7)$$

In QAM-16 modulation, carrier frequencies have twelve phase values and 3 amplitude values, in this case, each position of the signal vector corresponds to a four-bit binary symbol (pulse), in which case Gray code is used. Therefore, neighboring pulses (symbols) differ in the bit value in only one bit, which minimizes the probability of an error per symbol.

The paper presents the investigated block diagram of QAM (QAM) (Fig. 3).

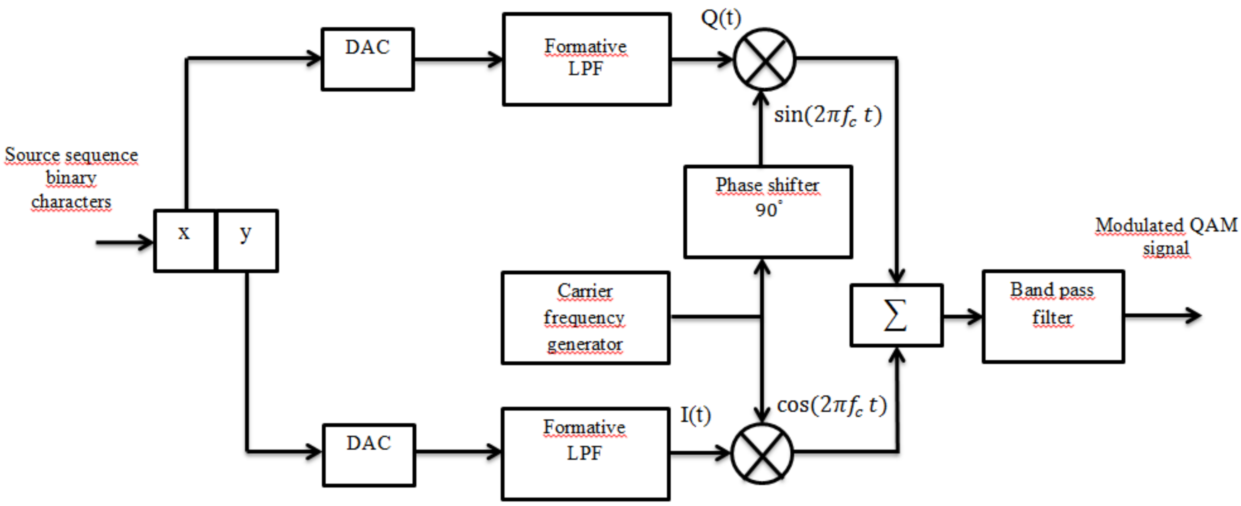

Fig.3. Structural diagram of QAM

The initial sequence of binary symbols of duration T is fed to the input of the modulator under study, then the initial sequence of binary symbols is divided into even (x) and odd (y) pulses using a shift register, after which the (x) and (y) pulses are fed to two DAC channels for digital-to-analog conversion with simultaneous formation of their spectrum in a digital filter (DF). The output smoothed signals of the DAC are fed to the LPF shapers, for the formation of manipulating pulses, after processing at the output of the LPF shapers, bipolar pulses I(t) and Q(t) are formed (Fig. 4 a, b), further formed bipolar pulses I(t) and Q(t) are fed to the first inputs of the multipliers, and quadrature signals are fed to the second inputs of the multipliers: sine U_s and cosine U_c (Fig. 4 c, d). The generated two-phase signals at the output of the multipliers are fed to the adder for summation, after summation they form a QAM signal (Fig. 4 e), then the modulated signal is passed through a bandpass filter to limit out-of-band radiation.

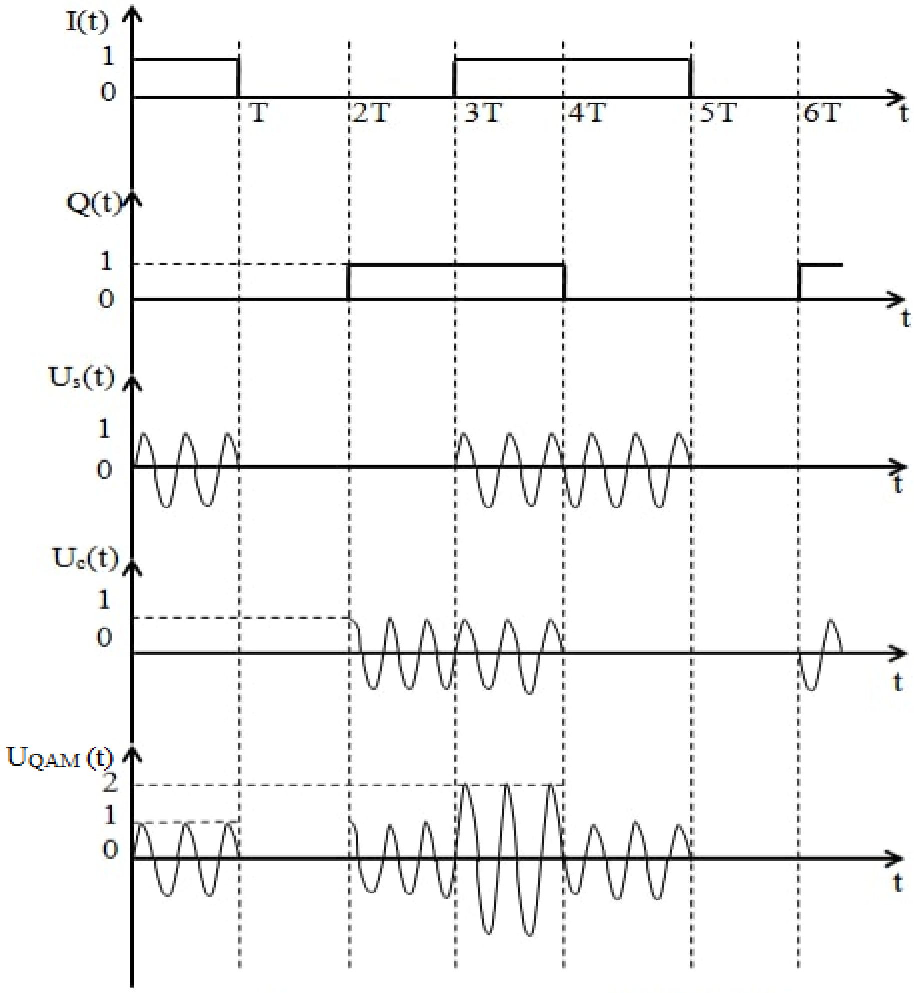

Fig.4. Formation of the QAM signal (QAM): a - bipolar pulse I(t) at the output of the LPF shaper; b - bipolar pulse Q(t) at the output of the LPF shaper; c - quadrature sine signal at the output of the phase shifter; d - quadrature cosine signal at the LFO output; e - quadrature amplitude-modulated signal.

The reliability of information transmission in digital systems is characterized by a statistical value - the probability of a bit error (Bit Error Rate - BER). BER is the probability of erroneous reception during the transmission of one bit of information, averaged over a statistically large amount of transmitted information [2].

Theoretically, the value that characterizes the efficiency of a digital communication system is the throughput [bps]. The bandwidth characterizes the amount of information that can be transmitted in a communication system per unit of time (with 100% confidence) [3].

In this paper, the dependence of the bit error probability on E_b/N_0 is theoretically investigated. The QAM error probability is investigated and calculated using (8) by the expression:

$$P_{ER(QAM)} = \frac{1}{\sqrt{2\pi}} \int_{\sqrt{(1-p)^{E_b}/_{N_0}}}^{\infty} (-\frac{U^2}{2}) du \quad (8)$$

P_{ER} – error probability

$P_{ER\,(QAM)}$ – bit error probability of the QAM modulation signal

$$P_{ER(QAM)} = \frac{1}{\sqrt{2\pi}} \int_{\sqrt{E_b/_{N_0}}}^{\infty} exp(-\frac{U^2}{2}) du = Q(\frac{E_b}{N_0}) \quad (9)$$

Here Q(x) is an additional error function, P=cosθ is the temporal cross-correlation coefficient between S1(t) and S2(t) signals,

where: θ-angle between signal vectors S_1 and S_2

$\theta = \pi$, so P=1, for QAM $\theta = \pi/2$ то P=0.

Bit error probabilities from E_b/N_0 for various 16.64 and 256-QAM are calculated using expression (9) and the calculated values are summarized in Table 1.

Table 1.

№	$P_{ER(QAM)}$	E_b/N_0, dB		
		16QAM	64QAM	256QAM
1.	1	0	0	0
2.	0,75	4,5	7,5	8
3.	0,5	6,5	8	11
4.	0,25	7,7	10,5	12,5
5.	0,1	8,5	11,4	14
6.	0,075	9,5	12,5	15,6
7.	0,05	10,2	13,7	16,6
8.	0,025	11	14,5	17,6
9.	0,01	11,5	15,1	18,4
10.	0,0075	12	16	19,6
11.	0,005	12,5	16,5	20
12.	0,0025	12,9	17	20,4
13.	0,001	13	17,2	21
14.	0,00075	13,3	17,7	21,5
15.	0,0005	13,7	18	22
16.	0,00025	13,8	18,2	22,2
17.	0,0001	14,1	18,5	22,5
18.	0,000075	14,2	18,8	22,8
19.	0,00005	14,4	19	23
20.	0,000025	14,6	19,1	23,2
21.	0,00001	14,7	19,3	23,4
22.	0,0000075	14,8	19,4	23,5
23.	0,000005	14,9	19,5	23,7
24.	0,0000025	15	19,7	23,9
25.	0,000001	15,1	19,9	24,1
26.	0,00000075	15,2	20	24,2
27.	0,0000005	15,3	20,1	24,3
28.	0,00000025	15,4	20,2	24,4

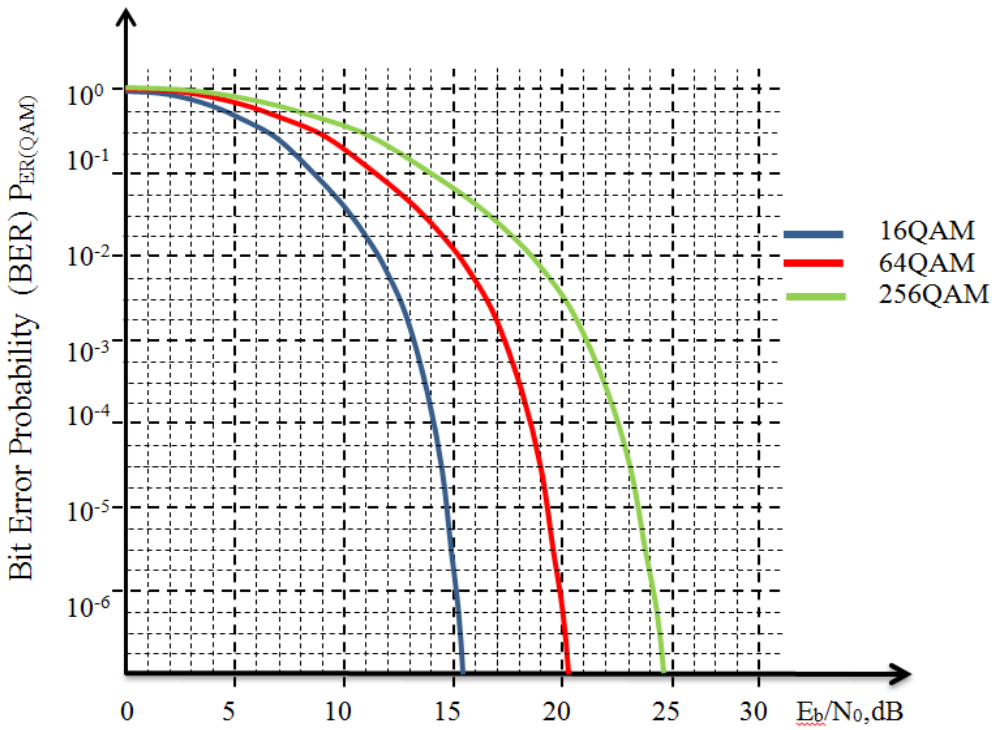

Figure 5 shows a plot of bit error probability versus E_b/N_0 on a logarithmic scale.

As a result of the study, the following conclusions can be drawn: with an increase in the positioning of the QAM signal, the probability of a bit error increases and with an increase in E_b/N_0, it will be possible to transmit a large number of symbols, that is, it is possible to provide noise-resistant reception of digital signals.

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