Investigation of the modulation type's influence on the DVB-T signals quality

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Abstract – **In this paper are made and described studies that represent the influence of key critical factors, ranging from RF performance characteristics, such as error vector magnitude (EVM), modulation error ratio (MER), through to roll-off and FEC for M-ary QAM modulation of subcarriers in the OFDM signal.**

Keywords – **DVB-T, EVM, BER, S/N, roll-off.**

I. Introduction

Advanced digital terrestrial systems behave quite differently when compared to traditional analog TV as the signal is subjected to noise, distortion, and interferences along its path. The secret to maintaining reliable and high-quality services over DVB-T transmission systems is to focus on critical factors that may compromise the terrestrial reception. Once reception is lost, the path to recovery isn't always obvious. The problem could be caused by MPEG table errors, or merely from the RF power dropping below the operational threshold or the cliff point. RF problems can include any of the following: terrestrial RF signal reflections, poor noise performance, or channel interference [1-4]. The results are based on the recent analytical research by used laboratory tests and theoretical analysis.

II. Mathematical analysis

This mathematical analysis is made according to the international standard requirements [1], [2] for terrestrial radio and television broadcasting and the characteristic parameters and features of the broadcasting in Republic of Bulgaria. The researches are for the main figures of merit and factors of OFDM modulation signal with channel frequency and 16-QAM/ 64-QAM modulation of the subcarriers.

A. Calculation of E_b/N_0

$$E_b/N_0 \text{ [dB]} = C/N - k_{RS} - k_{QAM}, \text{ where} \quad (1)$$

E_b/N_0 is the energy per useful information bit E_b referred to the normalized noise power N_0;
C/N - carrier-to-noise ratio in-channel [dB];
k_{RS} - the factor for FEC to Reed-Solomon [dB];
k_{QAM} - the factor for the QAM modulation [dB].

When we study the dependence of E_b/N_0 of S/N can be used $k_{r\text{-}f}$, which gives the relationship between C/N and S/N:

$$S/N \text{ [dB]} = C/N + k_{r\text{-}f}, \text{ where} \quad (2)$$

$k_{r\text{-}f}$ - the factor for the roll-off Nyquist filtering in the demodulator/receiver.

Then Eq.1 can be written as fallowing:

$$E_b/N_0 \text{ [dB]} = S/N - k_{r\text{-}f} - k_{RS} - k_{QAM}. \quad (3)$$

The values and the expressions for their obtaining for every parameter and factor are given in Table 1, where α is the roll-off factor by Nyquist skew, b is the number of bits per symbol and R_{RS} is Reed-Solomon code rate.

TABLE I
PARAMETERS AND FACTORS FOR QAM

modulation / Parameters and Factors	16-QAM		64-QAM	
M	16		64	
α	0,10	0,30	0,10	0,30
R_{RS}	188/204			
$b = log_2M$	4		6	
$k_{r\text{-}f} = 10lg(1\text{-}0,25\alpha)$	-0,1169	-0,3345	-0,1169	-0,3345
$k_{RS} = 10lgR_{RS}$	- 0,3547			
$k_{QAM} = 10lgb$	6,0206		7,7815	

B. Calculation of BER

For the calculation of the bit-error-rate (*BER*) for OFDM DVB-T signal with 16-QAM and 64-QAM modulations of the subcarriers we used expressions [1], [2]:

$$P_B = \frac{2^{(b-1)}}{2^b - 1}.P_S \text{ or} \quad (4)$$

$$P_B = \frac{1}{b}.P_S , \quad (5)$$

which give the relationship between Symbol Error Probability P_S and the Bit Error Probability P_b of QAM with M constellation points, arranged in a rectangular set, for b even.

The Eq.4 makes no assumption about the constellation mapping and is based on the probability that any particular bit in a symbol of b bits is in error, given that the symbol itself is in error. The Eq.5 assumes that an erroneous symbol contains just one bit in error. This assumption is valid as long as a Gray coded mapping is used and the *BER* is not too high. These equations give different results for symbols of two or more bits. The second approach is generally adopted because DVB systems employ Gray code mapping.

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As per Eq.5 when the received signal is distraught by Additive White Gaussian Noise (AWGN) there is a probability that any particular symbol will be wrongly decoded into one of the adjacent symbols. The P_S is given by:

$$P_S(E_b/N_0) = 2.(1-\frac{1}{\sqrt{M}})\cdot erfc[\sqrt{\frac{3b.(E_b/N_0)}{2.(M-1)}}]$$

$$\times\{1-\frac{1}{2}.(1-\frac{1}{\sqrt{M}}).erfc[\sqrt{\frac{3b.(E_b/N_0)}{2.(M-1)}}]\}, \quad (6)$$

where erfc(x) is the complimentary error function given by:

$$erfc(x) = (2/\sqrt{\pi}).\int_x^{\infty} e^{-t^2}dt. \quad (6a)$$

For practical purposes Eq.6 can be simplified by omitting the (generally insignificant) joint probability term to give the approximation:

$$P_S(E_b/N_0) = 2.(1-\frac{1}{\sqrt{M}})\cdot erfc[\sqrt{\frac{3b.(E_b/N_0)}{2.(M-1)}}]. \quad (7)$$

This approximation introduces an error which increases with degrading E_b/N_0, but is still less than *0,1 dB* for 64-QAM at $E_b/N_0 = 10$ *dB*. As already stated, the above equations for Symbol Error Probability are based on certain simplifying assumptions which can be summarized as "the system is perfect except for the presence of additive white Gaussian noise", but within this rather generous constraint the equations for P_S are exact.

C. Calculation of EVM and MER

EVM and *MER* take into account the combined effects of *C/N*; transmitter, upconverter phase noise; impairments such as second and third order distortions; group delay; in-channel frequency response problems (amplitude tilt or ripple) and microreflections. *EVM* and *MER* measure essentially the same quantity and easy conversion is possible between the two measures if the constellation is known.

1) Calculation of EVM

For calculation of EVM, we use the relationship between *EVM* and *S/N* [5]. After performing the appropriate mathematical transformations we obtain the expression for *EVM*:

$$EVM = 10^{-\frac{S/N+k}{20}}.100\%, \text{ where} \quad (8)$$

k is the peak-to-average energy ratio (Table II). The Eq. 8 used to calculate the *EVM* is directly from vector considerations of signal plus noise in relationship to the ideal constellation points of any M-QAM signal. The minus sign in Eq. 8 is necessary because *S/N* is the ratio of signal to noise whereas *EVM* is the ratio of noise to signal.

TABLE II
EVM VALUES FOR VARIOUS MODULATIONS

modulation	k
	dB
16-QAM	2,5527
64-QAM	3,6796

2) Calculation of MER

MER is the preferred measurement for the following reasons [1]:

- The sensitivity of the measurement, the typical magnitude of measured values, and the units of measurement combine to give *MER* an immediate familiarity for those who have previous experience of *C/N* or *S/N* measurement;
- *MER* can be regarded as a form of *S/N* measurement that will give an accurate indication of a receiver's ability to demodulate the signal, because it includes, not just Gaussian noise, but all other uncorrectable impairments of the received constellation as well;
- If the only significant impairment present in the signal is Gaussian noise then *MER* and *S/N* are equivalent (they are often used interchangeably).

The relationship between *EVM* and *MER* given by the expression:

$$EVM_V = 1/(MER_V.V), \quad (9)$$

where the peak to mean voltage ratio *V*, is calculated over a large number of symbols (10 times the number of points in the constellation is adequate if the modulation is random) and each symbol has the same probability of occurrence then it is a constant for a given transmission system. The value tends to a limit which can be calculated by considering the peak to mean of all the constellation points. Table III lists the peak-to-mean voltage ratios for the DVB constellation sizes. When expressed as simple voltage ratios MER_V is equal to the reciprocal of the product of EVM_V and the peak-to-mean voltage ratio for the constellation.

TABLE III
PEAK-TO-MEAN RATIOS FOR THE DVB CONSTELLATION SIZES

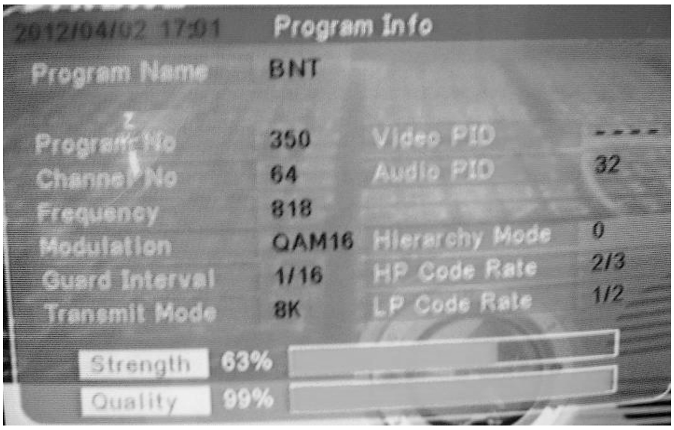
modulation	Peak-to-mean voltage ratio V
16-QAM	1 341
64-QAM	1 527

III. SIMULATION INVESTIGATION

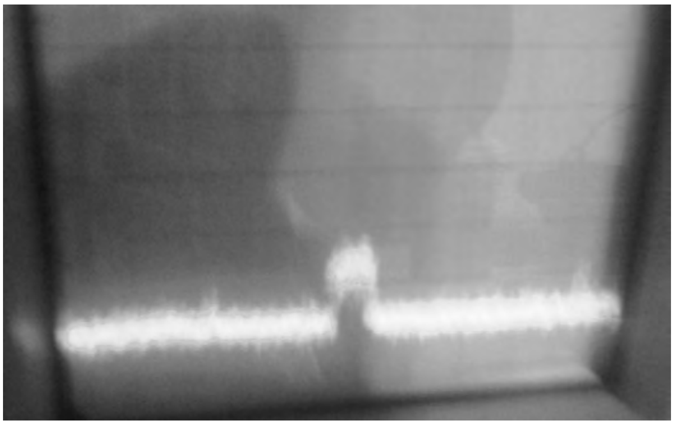
In this section the simulated researches, of main parameters of DVB-T signals with 16-QAM and 64-QAM modulations of the subcarrier, are made for an existing (real-life) channels in the area of the city of Sofia (Figs.1 and 2). The research uses the mathematical dependences from above and its results are given in tables and graphics.

On Fig.1a is shown a picture with the parameters of received television channel by D/K standard at a frequency of 818 MHz (ch.64), and on Fig1b – the signal's spectrum. Table IV contains the numeric results from the simulation research for E_b/N_0, *SER, BER* and *EVM* at an amendment of *C/N* from 2÷30dB and respectively *S/N* from 1,88-29,88dB at α=0,1 [6].

Fig.2a shows a picture with the parameters of received television channel by D/K standard at a frequency of 626 MHz (ch. 40), and Fig2b - the signal's spectrum. Table V gives the numeric results of the simulation research [7] for E_b/N_0, *SER*,



a) Menu for ch.64 (16-QAM)



b) Spectrum ch.64 (DVB-T)

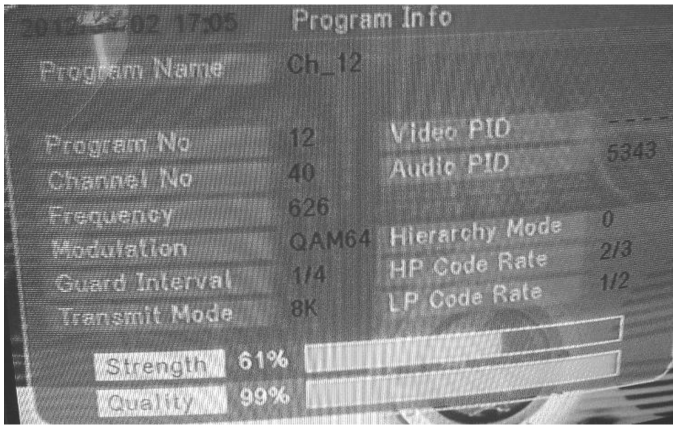
Fig.1. ch.64 (DVB-T)

TABLE IV
16-QAM VALUES

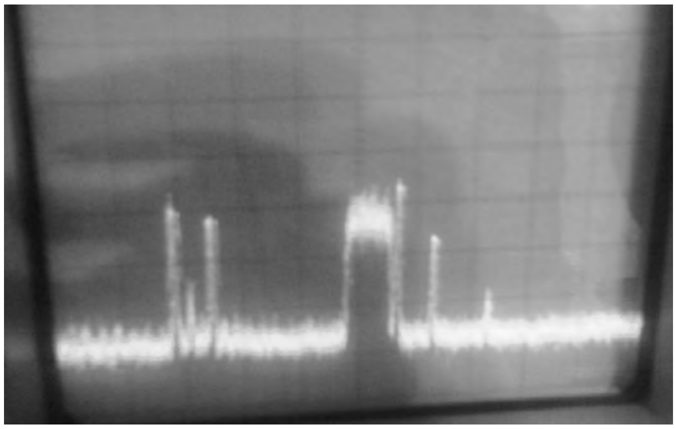
C/N dB	*S/N* dB	E_b/N_0 dB	*SER*	*BER*	*EVM* %
2	1,8831	-3,6659	0,3743	0,1995	60,01
4	3,8831	-1,6659	0,3153	0,1681	47,67
6	5,8831	0,3341	0,2469	0,1316	37,86
8	7,8831	2,3341	0,1732	0,0923	30,08
10	9,8831	4,3341	0,1027	0,0547	23,89
12	11,8831	6,3341	0,0472	0,0251	18,98
14	13,8831	8,3341	0,0146	7,79E-03	15,07
16	15,8831	10,3341	2,46E-03	1,31E-03	11,97
18	17,8831	12,3341	1,61E-04	8,60E-05	9,51
20	19,8831	14,3341	2,39E-06	1,27E-06	7,56
22	21,8831	16,3341	3,37E-09	1,80E-09	6,00
24	23,8831	18,3341	1,16E-13	6,17E-14	4,77
26	25,8831	20,3341	0	0	3,79
28	27,8831	22,3341	0	0	3,01
30	29,8831	24,3341	0	0	2,38

BER and *EVM* at an amendment of *C/N* from 2÷30 dB and respectively *S/N* from 1,88-29,88 dB at α=0,1.

The numeric results are shown graphically in Figs.3, 4 and 5, while in both cases (16-QAM/ 64-QAM) after the Viterbi and Reed-Solomon decoding *BER* is low (10^{-9} ÷10^{-11}) - for *S/N* between 22 and 28 dB. That confirms itself through the



a) Menu for ch.40 (64-QAM)



b) Spectrum ch.40 (DVB-T), ch. 36 and ch.41 (PAL-K)

Fig.2. ch.40 (DVB-T)

TABLE V
64-QAM VALUES

C/N dB	*S/N* dB	E_b/N_0 dB	*SER*	*BER*	*EVM* %
2	1,8831	-5,4268	0,5629	0,2871	52,71
4	3,8831	-3,4268	0,5298	0,2702	41,87
6	5,8831	-1,4268	0,4878	0,2488	33,26
8	7,8831	0,5732	0,4351	0,2219	26,42
10	9,8831	2,5732	0,3704	0,1889	20,98
12	11,8831	4,5732	0,2941	0,1500	16,67
14	13,8831	6,5732	0,2103	0,1073	13,24
16	15,8831	8,5732	0,1281	0,0654	10,52
18	17,8831	10,5732	0,0611	0,0312	8,35
20	19,8831	12,5732	0,0200	0,0102	6,64
22	21,8831	14,5732	3,68E-03	1,88E-03	5,27
24	23,8831	16,5732	2,76E-04	1,41E-04	4,19
26	25,8831	18,5732	5,03E-06	2,56E-06	3,33
28	27,8831	20,5732	9,89E-09	5,04E-09	2,64
30	29,8831	22,5732	5,74E-13	2,93E-13	2,10

indication for Quality on Figs.1a and 2a, which reaches 99%.

For low values of *S/N* (1,88÷19,88 dB) *BER* is very high and the receiving is either with errors or not possible, and *EVM* amends from 7,3% to 0,92%. For *S/N* ≥23 dB *EVM* values are almost equal. At an *S/N* =29,88 dB for 16-QAM is *EVM*=2,38% and for 64-QAM is *EVM*=2,1%.

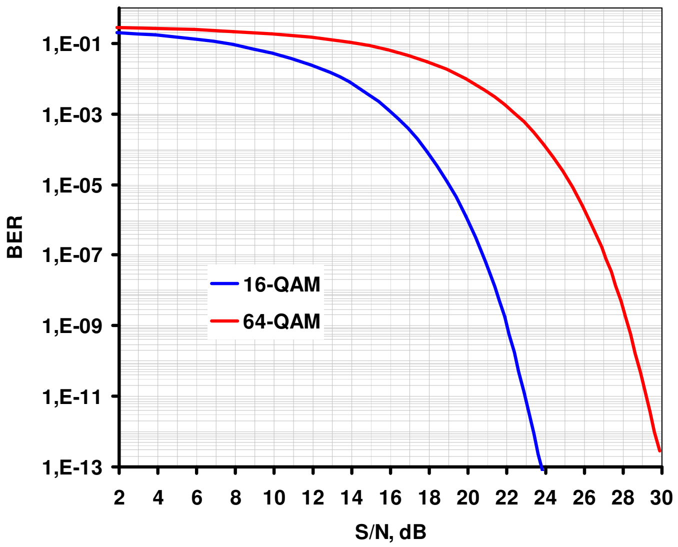


Fig.3. *BER=func(S/N)*

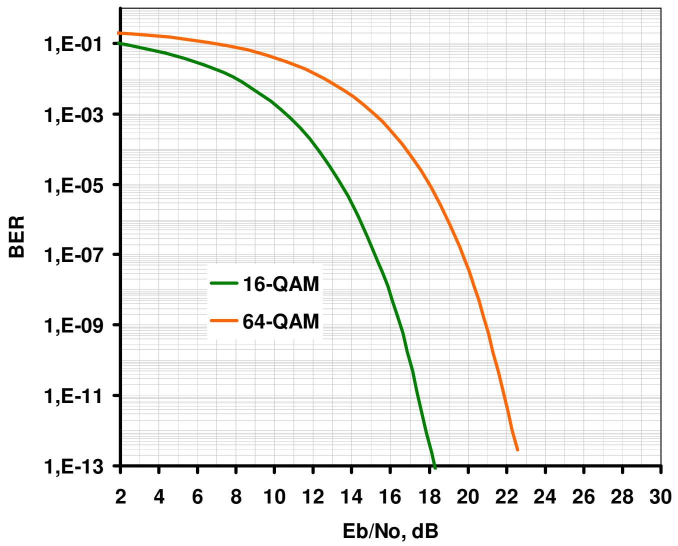


Fig.4. *BER=func*(E_b/N_0)

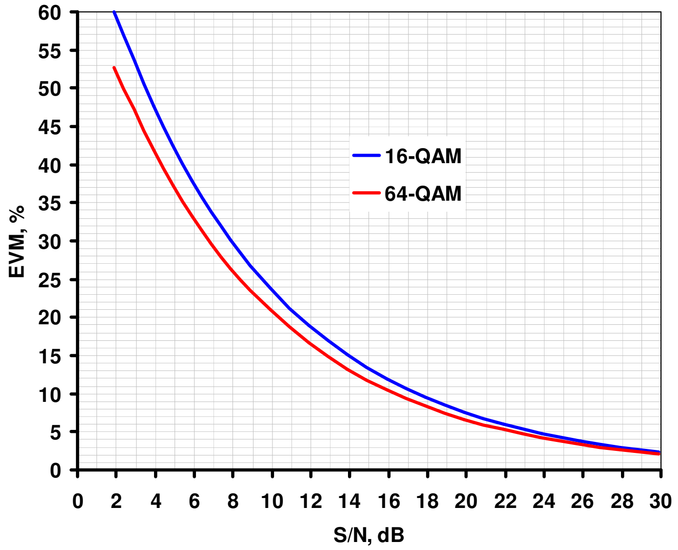


Fig.5. *EVM=func(S/N)*

The operation mode is in both cases 8k and the modulation non-hierarchical. There is also a difference between the levels of received signals (level of ch.64 is less than a one of ch.40). Near to the ch.40 is transmitted an analog television channel (ch.41 with picture carrier 631,25 MHz - PAL-K), which in some DVB-T receivers causes interference that deteriorate the researched parameters and mostly *BER* (which increases). That makes receiving ch.40 impossible. Methods and means for the elimination of this problem and rising of *S/N* and reduction of *BER* are an object of review in the second paper at the conference.

IV. Conclusion

It should be mentioned that for QAM systems DVB only employs Gray coding within each quadrant, the quadrant boundaries are not Gray coded, and the mapping is partially differentially coded. Further work is required to establish the exact P_S to P_B relationship for this combination of mapping and coding [1], [2], [8], [9].

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