THEORETICAL AND EXPERIMENTAL DETERMINATION OF SOME PARAMETERS OF THE SIGNALS IN DVB-T RECEPTION

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Abstract

The article discusses some problems with the terrestrial reception of radio and television digital signals (DVB-T) in the single-frequency (SFN) network. The reception is carried out with a Yagi antenna for four channels (23, 27, 40, 49). Mathematical express-ions for basic parameters (BER, MER, and SNR) are proposed and derived, characterizing the quality and reliability of reception of radio and television signals from first-generation digital multiplexes. The constellation diagrams for TV channels are presented at the receiving location from nearby and remote transmitters. The theoretical and experimental results were obtained in the Rice and Relay model of the transmission channel. Presented are graphical, tabular and photo data for four channels of considered digital multiplexes operating in the UHF band with different modulations of subcarriers.

1. INTRODUCTION

Nowadays bigger and bigger part of the radiocommunication systems transmit digital signals: television, radio, data. The project for video broadcasting (DVB) was created in the distant 1993 by representatives of radio and television providers, manufacturers, network operators and regulatory agencies [1]. In the next years several regulatory documents were created by international and European organizations (ITU, ETSI, CENELEC), that were accepted also by national agencies and institutions, where in Bulgaria this is BIS (Bulgarian Institute for Standardization). For the normal functioning of every radiocommunication system, it is necessary for its parameters for broadcasting as well as for receiving signals to correspond to the standardized values. Depending on the environment (air, cable) and place (space, ground) of the distribution of signals, the DVB systems and the corresponding DVB standards are divided in tree types: : DVB-S/S2, DVB-T/T2 and DVB-C/C2 [1, 2, 3, 4].

Over the years, the DVB technology turned into inseparable part of the global broadcast of satellite, cable, ground and IP based services. When a new specification is completed from DVB, it is published as BlueBook, after which the document is usually published as official standard by ETSI [5].

Every DVB system allows for digital signals to be broadcasted or received with MPEG or HEVC compression, where the resolution is SD or HD. The requirements for providing higher and higher quality and reliability of the information lead to constant refinement of DVB systems, improvement of their parameters and application of different methods for processing their signals, protection from failures and control. Since there is a lot common between the three types of DVB systems, it is possible to perform transmodulation from DVB-S/S2 and DVB-T/T2 to DVB-C/C2, which is widely used in the systems for cable television (CATV/HFC).

They are the same for processing the signals in “encoding/decoding the source”, but for “encoding/decoding the channel” they have differences in the type of used modulation and the way of forming of the digital stream before the modulation. In Base Band (BB) the signals are digital, where they are compressed MPEG-2, MPEG-4 or HEVC. After the modulation (QPSK/8-PSK/M-QAM/COFDM) the signal is converted frequency-wise for certain channel, where it is already in analog form [4]. In this sense, the control of the parameters of DVB systems for assurance of their normal functionality is done by measurement of BER, MER, C/N, U_s, V_{bit} and etc., for one or more carrying frequencies in certain frequency range.

The current investigation is done for the determination of these parameters by transmission of digital signals according to the standard DVB-T in single frequency network (SFN). Some problems with aerial reception of digital signals from near and distant multiplexes by Ricean and Rayleigh model of the transfer channel are reviewed.

2. DIGITAL VIDEO BROADCASTING-TERRESTRIAL (DVB-T)

In terrestrial aerial digital television broadcasting (DVB-T) for one channel for the corresponding standard (B/G, D/K), 4-6 digital television channels can be broadcasted. This is achieved through compression of the information for each channel according to the method MPEG-2 or MPEG-4 and forming a transport stream (TS), following multiplexing and modulation. There is only one carrying frequency here, called central f_c. The standard DVB-T provides several work modes, provisionally labeled as 2k and 8k, where the theoretical count of subcarrying signals is 2^{11}=2048 (2k) and 2^{13}=8192 (8k). In practice, however, lower amount of subcarrying signals are used. After addition of the pilot signals, the bits for internal and external protection from failures and synchronization to the useful digital stream (of the video signal, sound signals and the transmitted additional data), the count of subcarrying frequencies reaches up to 1705 (2k) and 6817 (8k). The 2k mode is meant for use in single transmitters and in small single frequency networks (SFN) with small distance between the transmitters. The 8k mode can be used for single transmitters as well as for large single frequency networks with larger distance between the transmitters. Every subcarrying signal is modulated separately with one symbol, where for each cycle of the modulation all subcarrying signals transmit one OFDM symbol. Three ways for modulation of every subcarrying signal are used: QPSK, 16-QAM or 64-QAM. The spectrum of the OFDM signal represents a sum of the spectra of the separate modulated subcarrying signals, which mutually overlap each other. The maximum of certain subcarrying signal matches with the minimums of the spectra of the neighboring modulated subcarrying signals. In fact, the OFDM signal is similar to Gaussian noise. The whole energy of the spectrum is focused in the frame of the television channel with frequency band 8MHz (UHF band), 2k and 8k modes and guard interval Δ′, whose place in OFDM symbol is showed in Fig. 1. In Table1 the values for the main parameters of the OFDM signals are presented and the mathematical dependencies between them are:

$$T_{OFDM} = \Delta + T_u, \ [\mu s] \tag{1}$$

$$(T_u/T_{OFDM}) = T_u/(\Delta + T_u) = T_u/[T_u/(1+\Delta/T_u)]$$
$$= (1+\Delta/T_u)^{-1} = (1+\Delta')^{-1} \tag{2}$$

$$\Delta' = \Delta/T_u = 1/2^n, \tag{3}$$

where $n = 2, 3, 4, 5$.

$$T_{OFDM}^{(1/4)} > T_{OFDM}^{(1/8)} > T_{OFDM}^{(1/16)} > T_{OFDM}^{(1/32)} \tag{4}$$

$$T_u^{(1/4)} = T_u^{(1/8)} = T_u^{(1/16)} = T_u^{(1/32)} \tag{5}$$

$$\Delta^{(1/4)} > \Delta^{(1/8)} > \Delta^{(1/16)} > \Delta^{(1/32)} \tag{6}$$

$$\Delta^{(1/4)} = 2\Delta^{(1/8)} = 4\Delta^{(1/16)} = 8\Delta^{(1/32)} \tag{7}$$

Table 1. OFDM parameters

Mode	8k			
Δ′	1/4	1/8	1/16	1/32
Δ *μs*	224	112	56	28
T_u *μs*	896			
T_{OFDM} *μs*	1120	1008	952	924
$D=(T_u/T_{OFDM})$	4/5	8/9	16/17	32/33

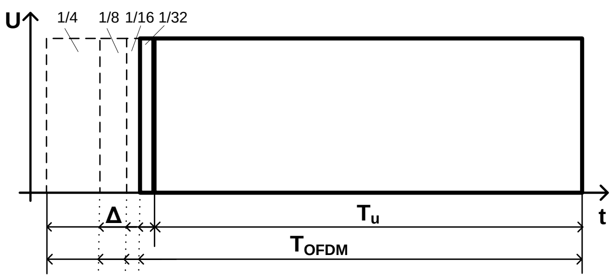

Fig. 1. Guard interval in OFDM symbol

QAM is the most popular modulation for subcarrying signals, where for DVB-T 16-QAM and 64-QAM are used. The output digital signal is formed through with orthogonal frequency division multiplexing (OFDM), respectively with coded orthogonal frequency division multiplexing (COFDM). COFDM is a special form of modulation with many carrying signals, for which one stream of data is transmitted through large number of subcarrying signals with lower data speed. It can deal with the high levels of the multipath distribution and the delays between the received signals. This leads to the concept for single frequency networks (SFN), in which many transmitters send the same signals with the same frequency, generating "artificial multipath". COFDM does similarly well also with co-channel narrowband interference, caused by the existing analog channels [4, 6, 7]. Furthermore, in reality COFDM represents a combination of modulation and multiplexing.

The formed COFDM signal with introduced energy dispersal, outer and inner coding/interleaving, mapping and pilots is converted with D/A converter in a signal with intermediate frequency. After that with UpC, the resulting analog signal is converted for some of the TV channels of the UHF range with width of the frequency band 8MHz. For achievement of certain distance (coverage), the radiofrequency signal (RF) is increased from power amplifier and is passed through a suitable feeder to the antenna (Fig.2a).

The reception of the DVB-T signals is performed with external and internal antenna and is processed in a DVB-T receiver, whose block diagram is shown on Fig.2b. The amplification of the received signals and the choice of precisely defined channel is performed in the tuner, which represents separate screened module integrated in the DVB-T receiver (set-top-box). Here, unfavorable influence is produced by the analog noise and nonlinear distortions. After that, the received signal for a chosen channel is processed by A/D converter and is transformed in digital form. Timing and frequency synchronization are performed in the next block and the guard interval in front of every symbol is removed and the symbol is processed by FFT for demodulation of OFDM [8].

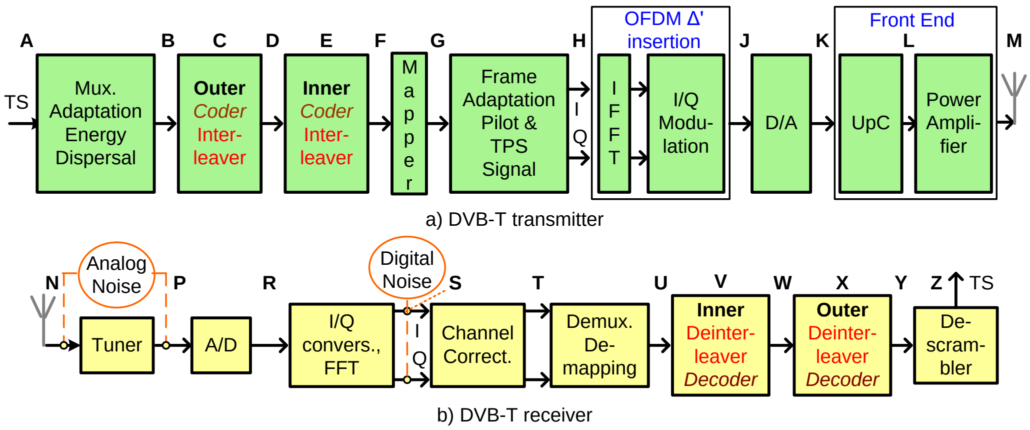

Fig. 2. Block diagrams of a DVB-T transmitter and receiver

The obtained I and Q components of the signal are subject to subsequent processing: channel correction, demulti-plexing and demapping, inner and outer deinterleaving/decoding, and descrambling (option). After that the decoded/ descrambled data is sent to the MPEG decoder. Here unfavorable influence is produced by the digital noise and Inter Symbol Interference (ISI). The protection from failures is done by Viterbi decoder and by RS decoder.

In real SFN network, the reception of DVB-T signals is of several transmitters working on one frequency (Fig.3). Through optimization of the density of the transmitters, the height and the location of the tower, the power of transmission, SFN can provide better coverage and economy of the spectrum. In addition, a satisfactory level of interference to and from adjacent networks can be maintained. However, the existence of at least two transmitters, even synchronized with GPS, makes the reception harder due to "natural" echoes conditioned by the lay, the buildings, the presence of trees, chimneys and etc. between the transmitter and the receiver.

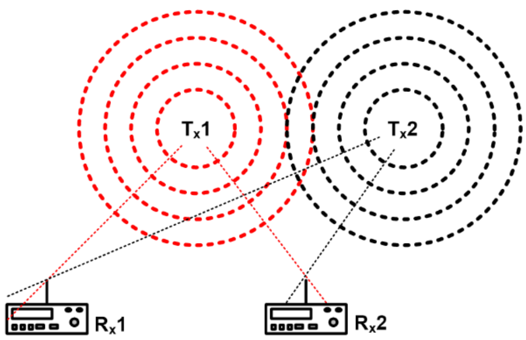

Fig. 3. SFN configuration

For a good reception, it is important that the echo arrives at the reception point within the protection interval, which is favorable, and at the places located at the edge of the coverage zone, a lower power will be needed. The signals coming from the transmitter will contribute to improvement of the common ration between the carrying signal and noise. The zones in radio shadow can be serviced also by secondary amplification, where "gap- filler" is used, representing a co-channel retransmitter.
During the installation and set up of every DVB-T transmitter, it is necessary to set up also the delay of

the signal, so that, at all places for reception in the coverage zone, the relative delays of all significant received signals (the main ones and their echoes) can be in the range of the guard interval. R_x1 receives the main signal from a transmitter T_x1 and the delayed and attenuated signal from T_x2. R_x2 receives the signals from T_x1 and T_x2 without differential delay [9].

The establishment of the level of influence of unfavorable factors on the DVB-T signal parameters and respectively decrease in the quality and reliability of the connection transmitted in the channel and subsequently received information, is done according to numerous regulatory documents. In these documents, the methods and means for experimental definition of the necessary values for BER, MER, S/N, END, EVM, C/N and etc. are presented. In [4] are presented "DVB-T measurement parameters and their applicability" for transmitter, network and receiver. The following parameters, which give an in-depth analysis of the various impacts (all deteriorating the signal), can be calculated [4, 6]:

a) Modulation Error Ratio (MER) - S, T and H test points:

$$MER = 10.lg\left\{\frac{\sum_{j=1}^{N}(I_j^2 + Q_j^2)}{\sum_{j=1}^{N}(\delta I_j^2 + \delta Q_j^2)}\right\}, \text{[dB]} \quad (8)$$

where I_j and Q_j are the ideal coordinates of the j^{th} symbol, δI_j and δQ_j are the errors in the received j^{th} symbol point and N is the number of symbols in the measurement sample.

b) Signal-to-Noise Ratio (SNR or S/N) – S, T test points:

$$SNR = 10.lg\left\{\frac{\frac{1}{N}\sum_{j=1}^{N}(I_j^2 + Q_j^2)}{\frac{1}{N}\sum_{j=1}^{N}(\sigma I_j^2 + \sigma Q_j^2)}\right\}, \text{[dB]} \quad (9)$$

where the σI_j and σQ_j are the error vector co-ordinates which represent the offset from the co-ordinates of the centre (mean value) of the actual received data for a specific constellation point, to the actual received data point j.

c) Bit Error Rate (BER) – from F to U or from E to V; W or X; Z. BER is the numerical value of Error probability P_B. From [4] and [6] the mathematical dependence is derived for Error probability:

$$P_B = A.erfc\left[\sqrt{C.(E_b/N_0)}\right].\left\{1 - B.erfc\left[\sqrt{C.(E_b/N_0)}\right]\right\}, \quad (10)$$

where for 16-QAM A=0,75; B=0,38; C=0,4 and for 64-QAM A=0,88; B=0,44; C=0,14.

3. THEORETICAL AND EXPERIMENTAL RESULTS

The reception of DVB-T signals is carried out with antenna from "wave channel" (Yagi) type, oriented in the horizontal and the vertical plane (in external and internal installation). The measurements were made with a specialized measuring instrument that allows to monitor and record the parameters and characteristics of the received first generation digital multiplex TV signals. The location of reception is the city of Sofia, where channel 23, 27 and 40 are from closely and channel 49 from far away placed transmitters. The theoretical and experimental results were obtained by two models of the transmission channel:

- Ricean = directional receiving antenna + reflected signals;
- Rayleigh = omnidirectional antenna reception + reflected signals.

In Table 2, the main parameters of the signals transmitted in every of the above-mentioned channels are mentioned as well as the calculated speeds of the digital streams in Mbps. For the goal according to [10], equation (2) and Table 1 the mathematical dependencies for net data rate V_{bit} are derived:

$$V_{bit} = SR\,.\,b\,.\,R_c\,.\,K_{RS}.\,(1+\Delta')^{-1} = SR\,.\,b\,.\,R_c\,.\,K_{RS}/(1+\Delta'), \text{[Mbps]}, \quad (11)$$

where $b=log_2M$, K_{RS} =188/204 and

$$(T_u/\,T_{OFDM}) = D = (1+\Delta')^{-1}. \quad (12)$$

Then

$$V_{bit} = SR\,.\,b\,.\,R_c\,.\,K_{RS}.D\,, [Mbps]. \quad (13)$$

On Fig. 4 is shown the graphical relation-ship of V_{bit} = func (channel, Δ'). The carrying frequencies of every channel are calculated according to the following formula:

$$f_{c,i+21} = 474 + i.B\,, \text{[MHz]} \quad (14)$$

where $i = 0, 1, 2, 3, \;, 48$ and B is channel bandwidth.

Table 2. Parameters of the channels

Parameters \ channel	23	27	40	49
f_c MHz	490	522	626	698
Modulation	64-QAM	16-QAM	64-QAM	64-QAM
B MHz	8	8	8	8
Mode	8k	8k	8k	8k
R_c	2/3	2/3	2/3	2/3
b	6	4	6	6
Δ'	1/4	1/16	1/4	1/4
V_{bit} Mbps	20,27	15,90	20,27	20,27

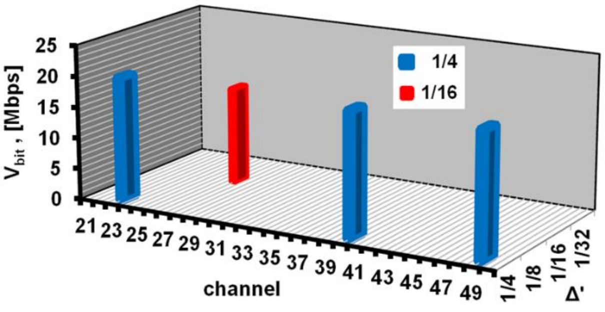

Fig. 4. *V_{bit}*=func (channel, *Δ'*)

The numerical values of the main parameters of the DVB-T signals for the four television signals are presented in Table 3 and the graphical relations between them on Fig.5 *BER=func*(*C/N*), Fig.6 *C/N and MER=func*(f_c) and Fig.7 U_s=*func*(f_c). For MER, C/N and U_s of the presented graphics, a comparison was made between the obtained values for Rayleigh and Ricean channels and those required by the standard [10] C/N_{min} and $U_{s\ min}$ - the lowest (Low) and highest (High) values of 5 referenced.

Table 3. Experimental results

channel / Parameters	23		27		40		49	
Model channel	Ricean	Rayleigh	Ricean	Rayleigh	Ricean	Rayleigh	Ricean	Rayleigh
C/N dB	31,8	12,5	25,6	4	32,2	10,7	8,4	0,1
MER dB	25,7	15,8	21,7	11,9	24,5	16	17	-
CBER	4,8E-3	7,1E-2	5,1E-3	6,8E-2	4,5E-3	6,3E-2	5,8E-2	-
VBER	<1E-7	6,5E-5	<1E-7	4,5E-3	<1E-7	7,9E-5	2,8E-5	-
U_s dBμV	57,2	37,9	51	28,7	58,3	35,9	35	26,5

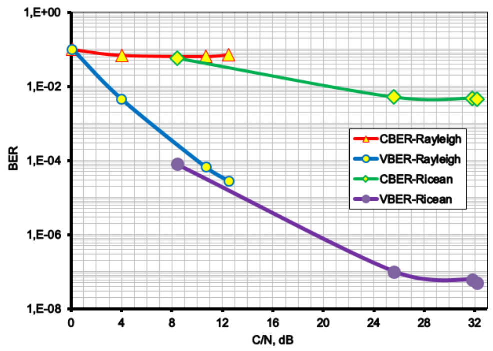

Fig. 5. BER=func (C/N)

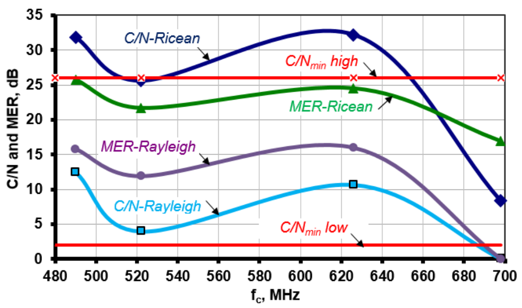

Fig. 6. C/N and MER=func (f_c)

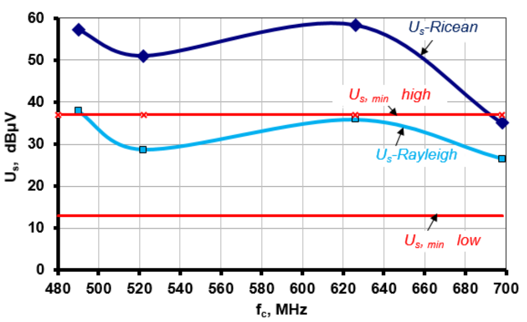

Fig. 7. U_s=func (f_c)

The deterioration of BER is more significant on the Rayleigh channel than on Ricean channel, because of the presence of disturbances by interference from echoes or from the signals from adjacent transmitters. For the distant transmitter (ch.49) even the level of the signal is <26,5 dBµV and an image of the constellations is missing (Fig.8), while for the closer one (ch.40) VBER=7,9E-5 and the level is 35,9 dBµV (Fig. 9).

Fig. 8. Constellation and spectral diagrams (ch.49-Rayleigh)

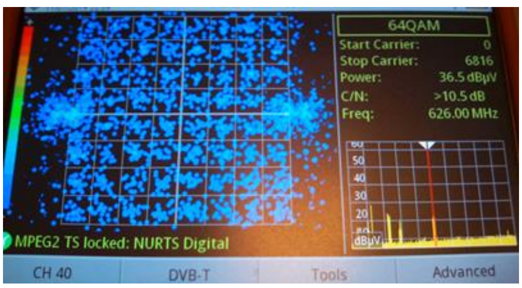

Fig. 9. Constellation and spectral diagrams (ch.40-Rayleigh)

For Ricean channel: for ch.49 the level of the signal is with around 10 dB higher compared to the Rayleigh channel, and VBER=2,8E-5 has an image of the constellations (Fig.10). For the near (ch.40) VBER<1E-7 and the level is 58,3 dBμV (Fig. 11).

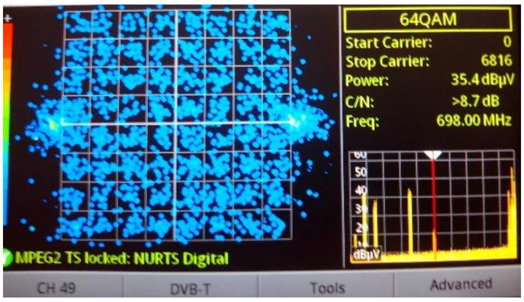

Fig. 10. Constellation and spectral diagrams (ch.49-Ricean)

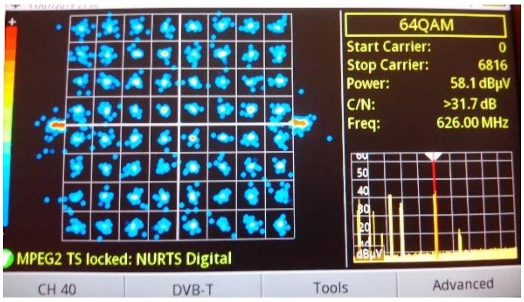

Fig. 11. Constellation and spectral diagrams (ch.40-Ricean)

4. CONCLUSION

The obtained theoretical and experimental results allow the formulation of measures to improve the DVB-T service at the receiving point. These measures can be divided into two: measures, that are undertaken by the operator-owner of the multiplexers and measures to be taken by the customer. In the first case, the measures are related to the broadcasting and retranslation of the signals, and in the second case, to their reception. Here are some of them:

a) Measures for transmission:

- changing the length of the protection interval, which, if Δ' is extended without change in the absolute duration of T_u, would accordingly reduce the capacity of the channel and V_{bit} (a longer Δ' could compensate longer echoes);
- extension of Δ' and T_u, which wouldn't lead to decrease in the capacity of the channel, but would make the processing of the signal difficult;
- in irregularly spaced networks the self-interference can be minimized by specific distribution of given transmitters over time.
- when there is a lack of coverage in the zone of service (deep valleys, tunnels, underground places or inside houses), a "gap-filler" can be used.

b) Measures for reception:

- finding a better spot for the antenna;
- usage of one or more directional antennas with higher gain;
- usage of antenna amplifier with low noise in case of reception with stationary antenna.

In SFN usually 8k mode is used (Table1), because the symbols and therefore the respective protective intervals are longer. The big SFN use the maximum Δ'=1/4 to support greater distances. For smaller regional SFN and for filling a gap, smaller Δ' can be used.

For the observation and control of some main parameters of the DVB-T signals on the customer side, some manufacturers allow for those parameters to be visualized on the screen of the TV through suitable software (Fig.12). This software is installed in the set-top-boxes (STB) [11] during their manufacturing or at later stage trough "Update".

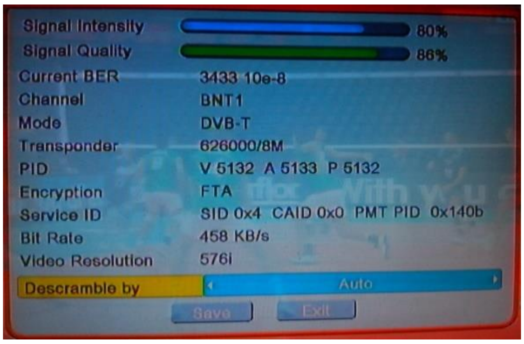

Fig. 12. DVB-T parameters from STB

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