# DVB-T Digital Terrestrial Television Transmission over Fading Channels

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**Abstract.** *The paper deals with the transmission of the digital television signal according to the DVB-T standard in SFN network over fading channels for the fixed reception. The laboratory transmission system for the real broadcasting based on R&S RF test and measuring equipments is presented including the transmission parameters setup. The results of broadcasting over Gausian, Ricean and Rayleigh channels and results of the echo impairments are presented and discussed with the theory and simulation results. The BER before and after Viterbi decoding and according to MER equal to S/N ratio in the channel from the constellation diagram were compared in all transmission experiments. Additional picture quality evaluation is presented using DVQL-W metric that monitors blockiness structures in MPEG-2 compressed pictures and gives notice of known "cliff-off" effect.*

## Keywords

Digital Terrestrial Transmission, Gaussian channel, Ricean channel, Rayleigh channel, DVQL, DVB-T.

## 1. Introduction

Digital Video Broadcasting – Terrestrial (DVB-T) is a technical standard developed by the DVB Project that specifies the framing structure, channel encoding and modulation for Digital Terrestrial Television (DTT) broadcasting. It is a flexible system that allows networks to be designed for the delivery of a wide range of services, from SDTV (Standard Definition TV) to HDTV (High Definition TV), fixed, portable, mobile and even handheld reception (in conjunction with standard DVB-H for mobile TV terminals that was built on the proven mobile performance of DVB-T).

DVB-T uses Coded Orthogonal Frequency Division Multiplex (COFDM) modulation. This type of modulation uses a large number of subcarriers and delivers a robust signal that has the ability to deal with various transmission channel conditions (fading included). DVB-T technical characteristics make DTT system flexible to operate in combination of:

- 3 modulation options (QPSK, 16-QAM, 64-QAM),
- 5 different FEC (forward error correction) rates,
- 4 Guard Interval options (1/32, 1/16, 1/8, 1/4),
- 2 modes of used carriers - 2k (1705) or 8k (6817),
- 3 channel bandwidths option (8, 7, 6) MHz.

Using different combinations of the above parameters a DVB-T network can be designed to match the requirements of the network operator, finding the balance between robustness and capacity. The use of COFDM modulation with the appropriate Guard Interval allows DVB-T to provide service in the Single Frequency Network (SFN). SFN is a network where a number of transmitters operate on the same RF frequency and must be synchronized in time and frequency. SFN can cover a country area or can be used to enhance indoor coverage using a simple "gap-filler".

## 2. Basics of the DTT Transmission

The distribution of DTT television programs by way of terrestrial transmitters is the classical technology of broadcasting. Received signal in good quality should be interpreted as the overall effect, the sum of various influences including the many possible disturbances created by noise, echoes, SFN co-channels and interference (see Fig. 1). The considerable directivity of the rooftop antenna, apart from the signal power obtained by the gain, can partially reduce echo impairments caused by reflection from hills, buildings etc. A good rooftop antenna guarantees the viewers service with satisfactory quality.

### 2.1 Gaussian Channel (AWGN)

The reception conditions within the service area can be described by the so-called "Gaussian channel" model, which is based on a direct signal path from transmitter to receiver. This channel is overlaid with additive white Gaussian noise (AWGN) which is mainly produced in the receiver itself.

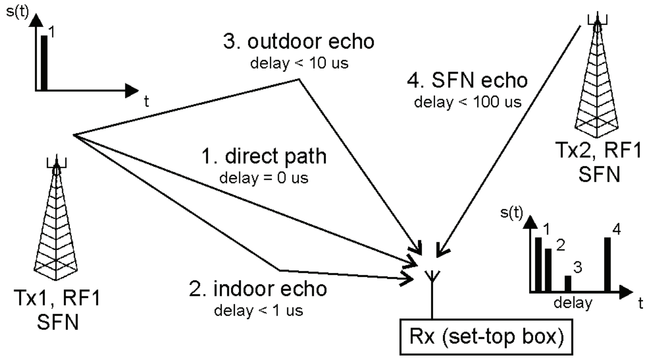



**Fig. 1.** Multipath reception in DTT – illustration of direct path and delayed echo signals influence on receiver response.

## 2.2 Ricean Channel

In order to include the impairments caused by echoes it is necessary to enlarge the channel model. The transmission path known as "Ricean channel", takes into account the effect of multipath signals in addition to noise and to the dominating direct signal path between transmitter and receiver. The statistics of these multipath signals are approximated by a Ricean distribution.

## 2.3 Rayleigh Channel

The movement of the receiver during reception can cause changes to the reception conditions, particularly inside buildings. Rod antennas on portable receivers bring no noticeable antenna gain or directivity. Requirements for terrestrial digital television in Europe define the stationary reception with a portable receiver. In comparison to the reception with a rooftop antenna this limitation means that it can not be taken for granted that a direct signal path would dominate. The simulation of the channel model describes the direct path eliminated. The transmission channel model with echoes of more or less equal priority is called "Rayleigh channel". The distribution of echoes corresponds to a Rayleigh distribution.

# 3. Transmission Channels Simulation

Reception with a rooftop antenna can be viewed as stationary reception and the directivity of the antenna can be used either for the selection of the direct signal or at least for choosing a dominant echo signal as the main reception signal. A typical home receiver operates with rooftop antenna, which should have a gain of approx. 7 dB (VHF) or 10 dB (UHF) [1].

As opposed to analogue television (ATV), in which echoes are more or less visible in the form of double contours on the screen, echoes in the case of DVB-T multiple signal reception cause an increase in intersymbol interference (ISI). This ultimately results in an increase in the bit-error rate (*BER*). This increase must then be corrected by increasing the transmission power [1], [2].

A simulation of the power requirements for the terrestrial DVB-T standard applied the following mathematical model to describe the channels with echoes – equations (1) and (2). A certain number of echoes can be taken into consideration. The output signal $y(t)$ of the channel model is described as a function of the input signal $x(t)$. As described before, the channel models are [3]:

- Ricean channel (RC)

$$y(t) = \frac{\rho_0 \cdot x(t) + \sum_{i=1}^{N_e} \rho_i e^{-j2\pi\Theta_i} x(t - t_i)}{\sqrt{\sum_{i=0}^{N_e} \rho_i^2}} \tag{1}$$

- Rayleigh channel (RL)

$$y(t) = \frac{\sum_{i=1}^{N_e} \rho_i e^{-j2\pi\Theta_i} x(t - t_i)}{\sqrt{\sum_{i=0}^{N_e} \rho_i^2}} \tag{2}$$

where $\rho_0$ is the attenuation in the direct signal path, $N_e$ is the certain number of echoes, $\rho_i$ is the attenuation in echo path $i$, $\Theta_i$ is the phase rotation in echo path $i$, and $t_i$ is the relative delay time in echo path $i$. The Ricean factor $K$ denotes the ratio of the signal in the direct path to the sum in all echo paths [1]:

$$K = \frac{\rho_0^2}{\sum_{i=0}^{N_e} \rho_i^2} . \tag{3}$$

For the measurement of the Ricean channel a Ricean factor $K = 10$ dB has been used, as suggested in [1]. In this case:

$$\rho_0 = 10\sqrt{\sum_{i=0}^{N_e} \rho_i^2} . \tag{4}$$

Ricean factor is $K = 0$ in case of Rayleigh channel simulation, as there is no direct path in this channel type. Factor $K$ equal to 10 was used in simulation.

A comparison of the results of simulations, in terms of carrier-to-noise ratio ($C/N$) required for quasi-error free (QEF) reception of a DVB-T signal in the Gaussian channel, with the respective values in the Ricean Channel shows, as expected, that the Ricean channel has higher requirements. The additional requirement is actually in the range of (0.3 – 1.1) dB, according to the system parameters (number of inner modulation states, convolutional code rate, hierarchy coding, etc.). An increase in the transmission power by a maximum of 30% is required to compensate the effect of echoes [1].

Like the Ricean channel, the Rayleigh channel, in comparison to the Gaussian channel, also requires higher *C*/*N* ratio. Simulation results show that for an error-free reception (again according to the system parameters) C/N is required up to 9 dB higher. An increase in the *C*/*N* by approx. 9 dB would require an eight times higher transmission power. This increase is not realistic [1].

The portable receiver therefore is affected by the lack of gain in the receiving antenna (gain of 10 dB in the UHF band, most relevant to the DVB-T) and by the signal deterioration in the Rayleigh channel. Further losses occur due to the fact that the reception antenna is often inside a building and often close to the ground level, while an antenna height of 10 m from a ground level is assumed in the calculation of the coverage.

The simulation results were computed on the assumption that a perfect correction of the channel frequency response has taken place in the terms of attenuation and phase rotation. Phase noise as a source of errors within the receiver was not considered. The *C*/*N* ratio was determined at which the channel *BER* before Viterbi for the rate of 2/3 or 3/4 is equal to or less than 3E-2 and *BER* after Viterbi decoding of inner error protection is equal to or less 2E-4. This condition finally leads to practically error-free signals (QEF) and at the input of the MPEG-2 demultiplexer BER is equal to or less than 1E-11 [4].

In case of the DVB-T transmission in the SFN with system parameters (64-QAM, mode 8k, convolutional code 2/3, Guard Interval 1/8) the required *C*/*N* ratio in dB and non-hierarchical modulation is equal to [3]:

- 16.5 dB for Gaussian channel (AWGN),
- 17.1 dB for Ricean channel (RC 20 paths),
- 19.3 dB for Rayleigh channel (RL 20 paths).

As explained before, the simulation of the Ricean channel represents an approximation of the actual conditions when receiving DVB-T signals via a rooftop antenna with high directivity. The Rayleigh channel is used to model the actual conditions when receiving DVB-T signals via stationary receivers, which have a rod antenna.

A close analysis of the numerical values leads to the following theoretical conclusions:

- The transition from the Gaussian channel to the Ricean channel, with the same type of modulation and constant code rate, results in necessary increase in the *C*/*N* by a maximum 1.1 dB,
- The transition from the Gaussian channel to the Rayleigh channel, with the same type of modulation and constant code rate, results in necessary increase in the *C*/*N* by a maximum 8.9 dB.

# 4. DVB-T Laboratory Transmission

The DVB-T transmission system deals with the transmitter and receiver sides (see Fig. 8). The transmitter side consists of the DVB-T/H test transmitter with variable DVB-T/H system parameters and MPEG-2 TS generator with the MPEG-2 MP&ML compressed video. Used RC profiles (see Fig. 2 and Tab. 1) and RL profiles (see Fig. 3 and Tab. 2) [5] accords to [3]. These are:

- R&S SFU DVB-T/H test transmitter (2111.2500.02),
- R&S SFU MPEG-2 TS generator (2111.2500.02),
- R&S SFU K-40 (noise generator) - AWGN,
- R&S SFU B-30 (fading simulator), - RC and RL.

The receiver side consists of the DVB-T test receiver with the MPEG-2 decoder option, MPEG-2 TS, digital video quality analyzer and set-top box. These are:

- Kathrein MSK-33 DVB-T test receiver Rx1,
- R&S DVQ video quality analyzer (2079.6003.03),
- STB Humax F3 FOX-T DVB-T home receiver Rx2.

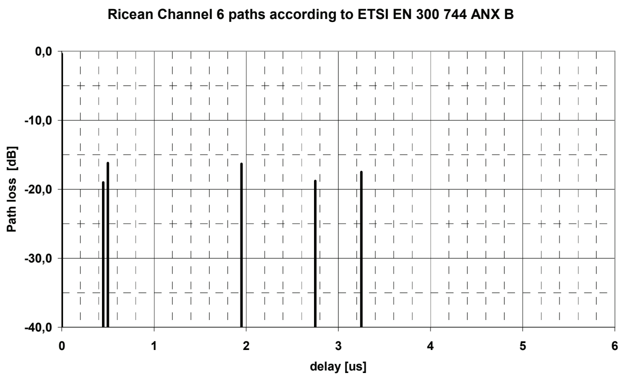
The MPEG-2 TS output of the DVB-T test receiver is connected to the MPEG-2 TS analyzer (picture errors check and its statistics). The picture analysis measures are available only if the PAT (Program Association Table) is decoded in the DVB-T test receiver.

The DVB-T system transmission parameters for all experimental measurements were set to European most convenient type of DTT broadcasting. These parameters are most characteristic for the SFN networks:

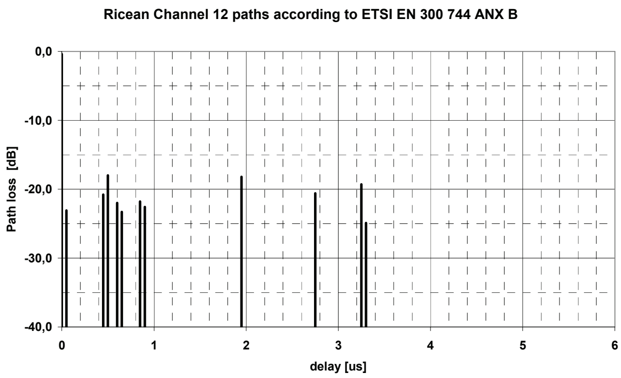
- RF level 60 dBuV (medium sensitivity of the Rx),
- 8 MHz channel (signal bandwidth of 7.608 MHz),
- 64-QAM modulation (max. TS of 22,11765 Mbit/s),
- 8k mode – 6817 subcarriers (fixed reception),
- 2/3 convolutional code rate (robust protection),
- 1/8 Guard Interval (medium size of SFN networks),
- non-hierarchical modulation (one TS transmission).

The results of achieved error-rates before and after Viterbi decoding were evaluated with the various *C*/*N* [dB] in the linear transmission channel. In advance the modulation error-rate *MER* [dB] from constellation diagram analysis and weighted digital video quality level *DVQL-W* [-] was automatically measured.

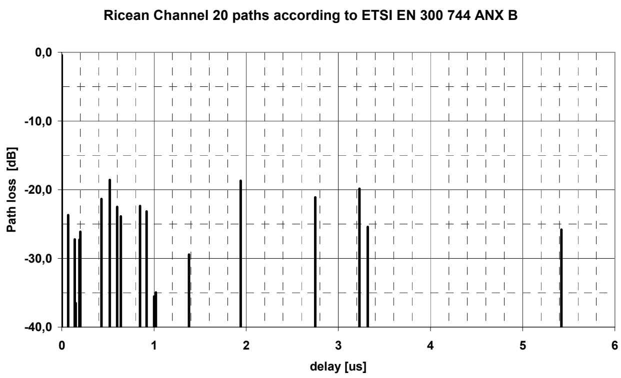
Measurements were done in the laboratory of digital television at the Department of Radio Electronics, Brno University of Technology.




a) RC6 ANX B profile (6 paths)




b) RC12 ANX B profile (12 paths)

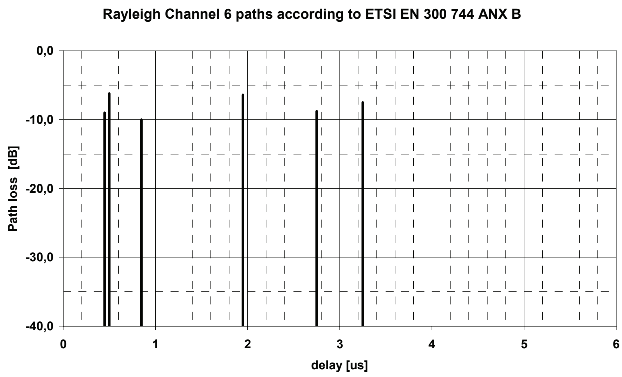



c) RC20 ANX B profile (20 paths)

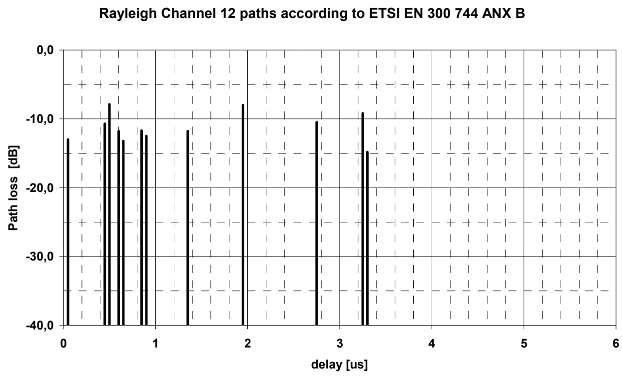
**Fig. 2.** Ricean channel profiles used for the transmission.

| Path number | Loss [dB] | Delay [us] | Phase [deg] |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 16.2 | 0.5 | 336.0 |
| 3 | 18.8 | 2.75 | 127.0 |
| 4 | 16.3 | 1.95 | 8.8 |
| 5 | 19.0 | 0.45 | 339.7 |
| 6 | 17.5 | 3.25 | 174.9 |

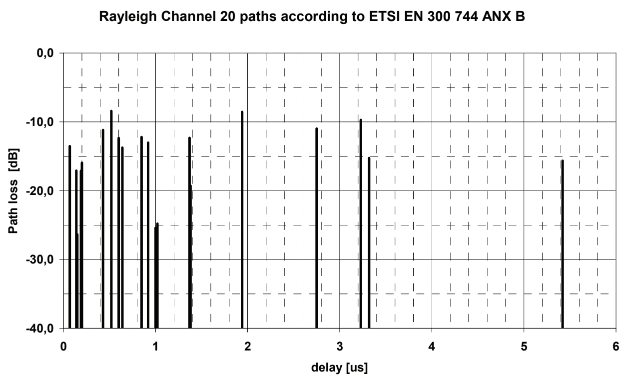
**Tab. 1.** Ricean channel profile RC6 ANX B specification (reduced number of 6 paths with the highest amplitude is often sufficient for practical implementation [3]).




a) RL6 ANX B profile (6 paths)




b) RL12 ANX B profile (12 paths)

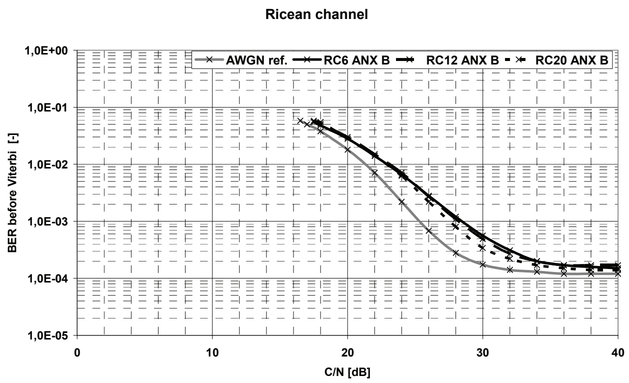



c) RL20 ANX B profile (20 paths)

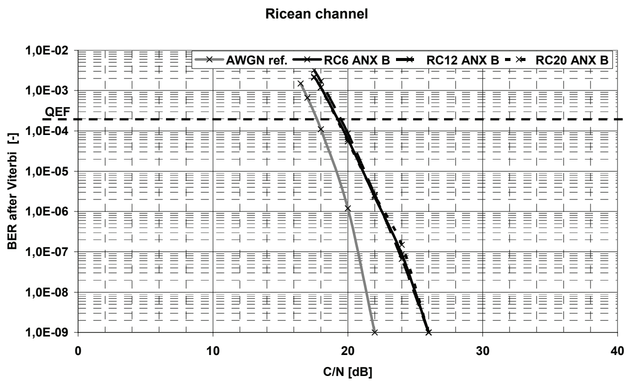
**Fig. 3.** Rayleigh channel profiles used for the transmission.

| Path number | Loss [dB] | Delay [us] | Phase [deg] |
|---|---|---|---|
| 1 | 6.2 | 0.5 | 336.0 |
| 2 | 8.8 | 2.75 | 127.0 |
| 3 | 6.4 | 1.95 | 8.8 |
| 4 | 9.0 | 0.45 | 339.7 |
| 5 | 7.5 | 3.25 | 174.9 |
| 6 | 10.0 | 0.85 | 36.0 |

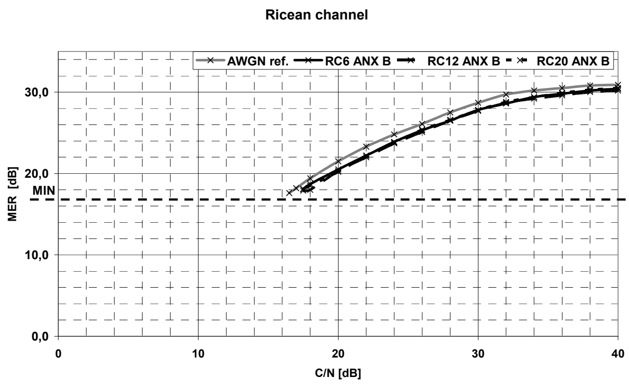
**Tab. 2.** Rayleigh channel profile RL6 ANX B specification (reduced number of 6 paths with the highest amplitude is often sufficient for practical implementation [3]).



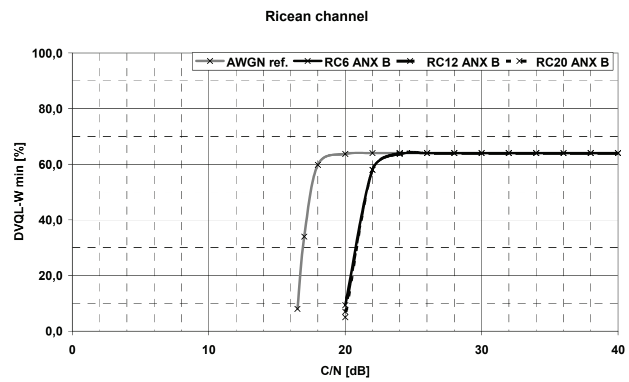

a) BER before Viterbi decoding (channel BER)




b) BER after Viterbi decoding

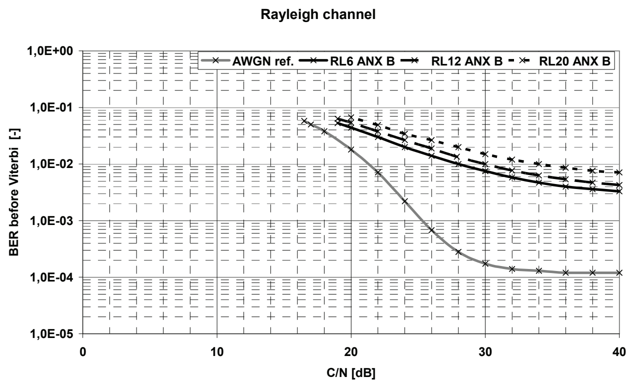



c) MER from constellation analysis

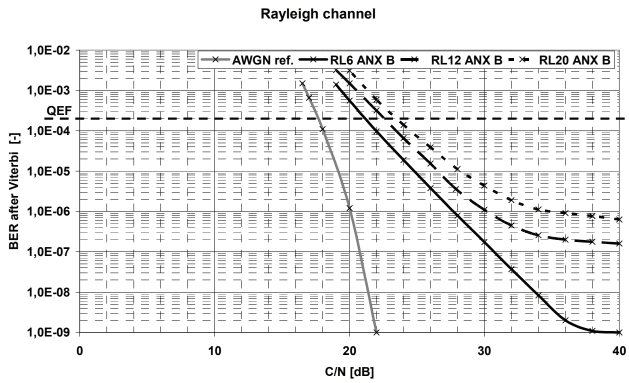



d) minimal DVQL-W metric with DVB-T "cliff off" indication

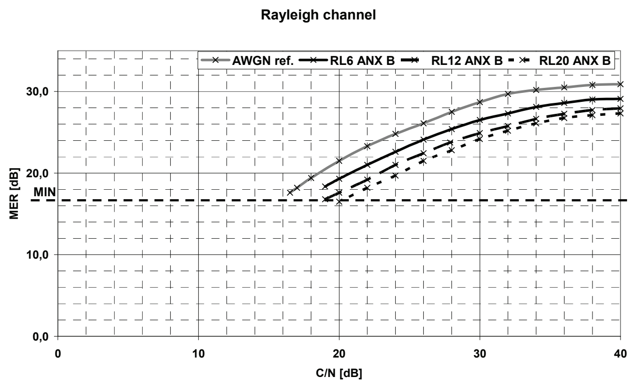
**Fig. 4.** Ricean channel results as a function of C/N ratio for fading channel profile "F1" (RC ANX B for the fixed reception without Doppler shift).



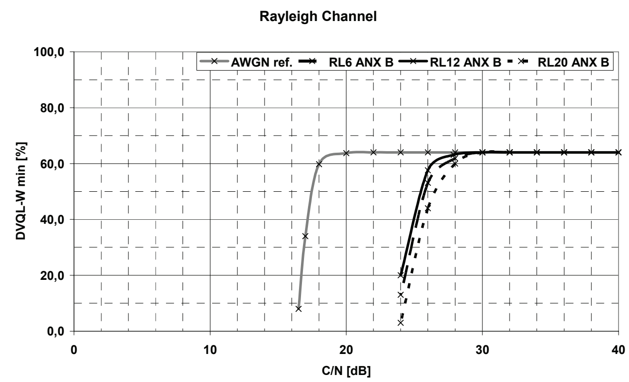

a) BER before Viterbi decoding (channel BER)




b) BER after Viterbi decoding

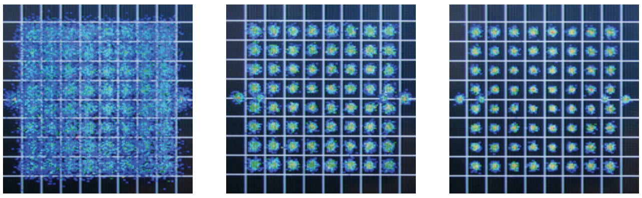



c) MER from constellation analysis

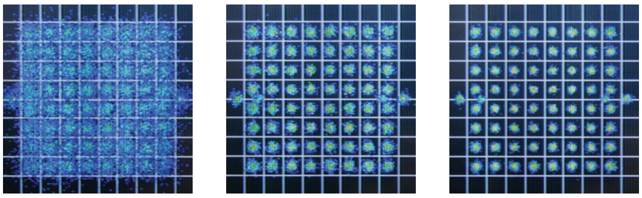



d) minimal DVQL-W metric with DVB-T "cliff off" indication

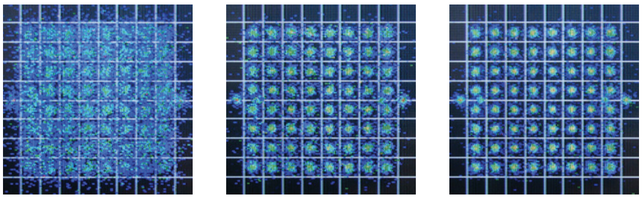
**Fig. 5.** Rayleigh channel results as a function of C/N ratio for fading channel profile "P1" (RL ANX B for the portable reception without Doppler shift).



a) AWGN with 20 dB MER = 21.5 dB | b) AWGN with 30 dB MER = 28.7 dB | c) AWGN with 40 dB MER = 30.9 dB



d) RC with 20 dB MER = 20.5 dB | e) RC with 30 dB MER = 27.8 dB | f) RC with 40 dB MER = 30.4 dB



g) RL with 20 dB MER = 16.5 dB | h) RL with 30 dB MER = 24.2 dB | i) RL with 40 dB MER = 27.3 dB

**Fig. 6.** Modulation error rate (MER) from the constellation of the DVB-T with 64-QAM modulation, various types of the transmission channels and different *C*/*N* ratio in the transmission channel.

## 5. Digital Video Quality Evaluation

The digital picture analyzer R&S DVQ operates in accordance to SSCQE (Single Stimulus Continuous Quality Evaluation) method [6]. Since the DCT related artefacts of a compressed video frames are always associated with blocking, SSCQE digital picture quality analyzer attempts to verify the existence of this blocking in the picture. This simple analysis of the pixel amplitude differences makes it possible to verify the existence of blocking structures in compressed or with distortion affected digital video frames.

The test procedure deals with the differences between adjoining pixels within a macroblock are formed. Pixel difference means that simply the amplitude values of adjacent pixels of the *Y* signal within a macroblock, and also separately those of the $C_b$ and $C_r$ signals are subtracted. The pixel differences of all macroblocks within a line are combined by adding them per line and frame. This finally provides information about the mean pixel difference in the horizontal and vertical direction of the frame within all macroblocks. The same process is repeated for $C_b$ and $C_r$, the color difference signals (details in [2]).

The comparison of pixel differences in a video sequence with a "good" picture quality and in one with a "poor" picture quality leads to the *DVQL-W* (Digital Video Quality Level - Weighted) objective quality evaluation [6].

a) frame without blocking artefacts DVQL-W between (80 – 60) indicates "good" video quality

b) frame with "blockiness" DVQL-W between (60 – 40) indicates "fair" video quality

c) frame with "error concealment" DVQL-W between (40 – 20) indicates "poor" video quality

d) "picture freeze" and "cliff off" DVQL-W between (20 – 0) indicates "bad" video quality

**Fig. 7.** MPEG-2 compressed digital video frame and illustration of the DVQL-W (Digital Video Quality Level – Weighted) metric progress while fading causes near "cliff-off" effect (loss of the DVB-T service availability).

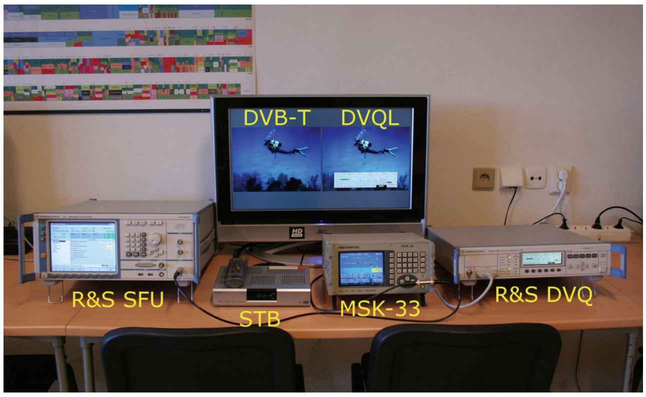



**Fig. 8.** Workplace for DVB-T laboratory transmission: transmitter TX (R&S SFU), measuring receiver RX1 (Kathrein MSK33), and control receiver RX2 (set-top box Humax F3-FOX T), MPEG-2 digital video quality analyzer (R&S DVQ).

## 6. Results

The analysis of the transmission via Gaussian channel (see Fig. 4 and Fig. 5 for the AWGN reference) leads to *C*/*N* equal to 17.8 dB to achieve *BER* after Viterbi on QEF border. According to *MER* (modulation error-rate) evaluated from the constellation analysis C/N is equal to 19.7 dB. In Gaussian channel the impairments are only by the mean of additive noise and results of *MER* are equal to *S*/*N* ratio in dB. The difference between *C*/*N* and *S*/*N* in the 8k mode is directly 0.33 dB due to the payload subcarriers power versus all subcarriers power of the OFDM multiplex (zero, payload, scattered, fixed, TPS). Practical results for stationary reception of the *C*/*N* are between 18 and 20 dB. The evaluated picture quality based on *DVQL-W* metric indicates the visible errors ("blockiness" or "blocking", so called "brick wall" effect) in the picture with the *C*/*N* equal to 19 dB or lower. This metric indicates the reception very close to the "cliff-off" (so called "fall of the cliff") effect when the DVB-T service is suddenly unavailable.

The analysis of the transmission via Ricean channel (see Fig. 4) leads to minimal *C*/*N* equal to 19.1 dB to achieve *BER* after Viterbi on QEF border. According to *MER* it is equal to 19.7 dB. The difference between the theoretical and simulated value and the practical result of the minimal *C*/*N* is 2.0 dB. The evaluated picture quality based on *DVQL-W* metric indicates the visible errors in the picture with the *C*/*N* equal to 22 dB or lower. The "cliff-off" effect comes with the *C*/*N* equal to 20 dB or less in the transmission channel. The number of Ricean channel paths (6, 12 or 20 echo paths) has a minimal effect on the achieved *BER*, *MER* and *DVQL-W*.

The analysis of the transmission via Rayleigh channel (see Fig. 5) leads to minimal *C*/*N* between 21.1 to 23.3 dB to achieve *BER* after Viterbi on QEF border. The number of analyzed echoes has 2.2 dB influences on minimal *C*/*N* *f*or QEF. According to *MER* it is between 19.6 and 23.3 dB. The difference between the theoretical and simulated value and the practical result of the minimal *C*/*N* is between 1.8 dB (6 echo paths) and 4.0 dB (20 echo paths). The evaluated picture quality based on *DVQL-W* metric indicates the visible errors in the picture with the *C*/*N* equal to 28 dB or lower. The "cliff-off" effect comes with the *C*/*N* equal to 23 dB or less in the transmission channel. An increasing number of Rayleigh channel paths has approx. 1 dB influence on "cliff-off" with lower number of the paths.

The influence of the fading on DVB-T with 64-QAM constellation is evident (see Fig. 6). A lesser *C*/*N* ratio leads to a lower *MER* in dB. A lower *MER* value is indicated with a higher constellation spread over modulation signals plane. Examples of the *DVQL-W* metric evaluation and typical blocking artefacts in DVB-T transmission and MPEG-2 video frames are illustrated (see Fig. 7).

# 7. Conclusion

All the transmission experiments were realized for the DVB-T system parameters that were set in the Transition Technical Plan to the DTT broadcasting presented by the Czech Telecommunication Office (CTU) to the Government of the Czech Republic in 2008 (64-QAM, 8k mode, convolutional code 2/3, GI 1/8, non-hierarchical).

DVB-T broadcasting pilot projects in the Czech Republic started in 2000 and regular broadcasting was launched in 2005 with one so-called "multiplex" (five programs, SDTV, MPEG-2). In the spring of 2008 the DVB-T service coverage included seven transmitters in five locations and SFN network (48% population). There is a plan for next four SFN networks and ASO (analogue TV switch-off) is planned in the autumn of 2011.

The presented results can be used for the transmission distortions analysis and evaluation of the DVB-T system parameters influence on transmitted signal in SFN network with multipath reception, echoes and SFN co-channels.

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