Simulation and Measurement of the Transmission Distortions of the Digital Television DVB-T/H

Part 2: Hierarchical Modulation Performance

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Abstract. *The paper deals with the second part of results of the Czech Science Foundation research project that was aimed into the simulation and measurement of the transmission distortions of the digital terrestrial television according to DVB-T/H standards. In this part the hierarchical modulation performance characteristics and its simulation and laboratory measurements are presented. The paper deals with the hierarchical oriented COFDM modulator for the digital terrestrial television transmission and DVB-T/H standards and possible utilization of this technique in real broadcasting scenarios – fixed, portable and mobile digital TV, all in one TV channel. Impact of the hierarchical modulation on Modulation Error Rate from I/Q constellations and Bit Error Rates before and after Viterbi decoding in DVB-T/H signal decoding are evaluated and discussed.*

Keywords

Hierarchical modulation, high priority path, low priority path, stream, HP, LP, COFDM, DVB-T/H.

1. Introduction

A short introduction to the DVB-T/H modulator performance was made in [1]. In this paper the *MER* (Modulation Error Rate) from the I/Q constellation and the *BER* (Bit Error Rate) before and after Viterbi decoding in DVB-T/H signal decoding were evaluated and discussed.

To ensure that reliable reception is still guaranteed even in poor conditions of the digital TV reception, hierarchical coding is provided as an option in DVB-T/H [2]. Without it a signal-to-noise ratio which is too low will lead to a hard "cliff-off" (starting from picture "blocking" and "freezing" to digital TV service unavailability). In the case of the frequently used DVB-T/H transmission with 64-QAM modulation and FEC convolutional rate 3/4 or 2/3, the limit of stable reception is at signal-to-noise ratio of just under 20 dB [3]. Furthermore, this condition is more critical with the fading channel transmission for portable and mobile reception without Doppler shift (in Gaussian channel approx. 18 dB, in Ricean channel "F1" approx. 19 dB and in Rayleigh channel "P1" approx. 22 dB [4]).

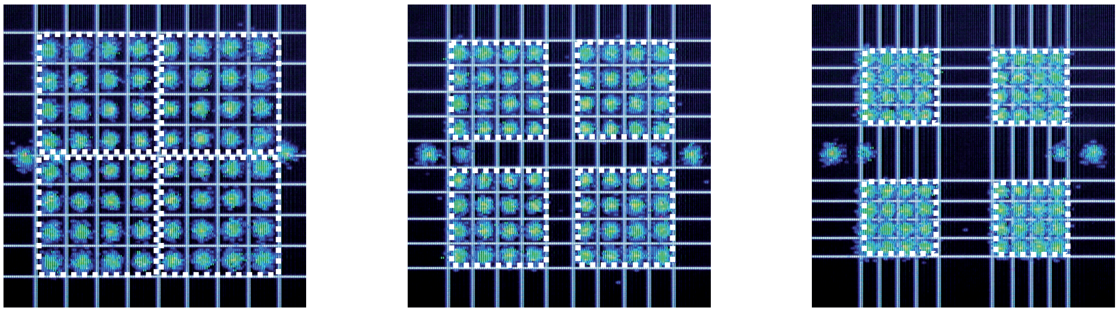
The Viterbi decoder can correct bit errors depending on the code rate selected in the convolutional encoder. The approximate condition for the QEF (Quasi-Error Free) reception, which corresponds to one error per hour, is defined as *BER* after Viterbi decoding equal to 2.10^{-4} or less [3]. This is the limit at which the subsequent Reed-Solomon decoder delivers an output *BER* of 1.10^{-11} or less. Slightly more noise or interference suffices and the DTV transmission breaks down (so called "cliff-off") [5].

2. Hierarchical Modulation Characteristic in DVB-T/H

If hierarchical modulation is used, the DVB-T/H modulator has two transport stream inputs and two FEC blocks.

One transport stream with a low data rate is fed into the so-called high priority path (HP) and provided with a large amount of error protection (selecting more robust code rate 1/2). A second transport stream with a higher data rate is supplied in parallel to the low priority path (LP) and is provided with less error protection (selecting less robust code rate 2/3). In principle both transport streams can contain the same program, but at different data rates (equal to amount of compression). On the high priority path the QPSK modulation is used which is particularly robust type of modulation (fit for mobile reception). On the low priority path a higher level of modulation is needed (16-QAM or 64-QAM) due to the higher data rate (fit for fixed or portable reception) [6].

In DVB-T/H the individual COFDM payload carriers are not modulated with different types of modulation. Instead, each payload carrier transmits a portion both of LP and HP (HP is transmitted as so-called embedded QPSK in 16 or 64-QAM modulation [3]) (see examples in Fig. 1).



a) b) c)

Fig. 1. Constellation diagrams of hierarchical modulation with factor α equal to a) α = 1 (looks like non-hierarchical), b) α = 2, c) α = 4. All the diagrams show QPSK modulation embedded in 16-QAM. Example measurements were done in mobile VU30 channel with C/N = 30 dB.

Considering bits and bytes, in a 64-QAM constellation it can be coded 6 bits per 64-QAM symbol. In hierarchical modulation, the 2 most significant bits (MSB) would be used for the robust mobile service, while the remaining 4 bits would contain, for example, a HDTV service. The first two MSBs correspond to a QPSK service embedded in the 64-QAM one. For example transmitted symbol is "110100", where the first "11" are used to code the HP service and the rest LSBs "0100" are used to code the LP service. The gross data rates for LP and HP thus have a fixed ratio of 4:2 to one another.

The net data rates are dependent on the code rate used. To make the QPSK of the HP more robust (less susceptible to interference) the constellation diagram can be spread at the I axis and the Q axis. A factor α equal to 2 or 4 increases the distance between the individual quadrants of the 64-QAM diagram - see again Fig 1 a) to c). The information about the presence or absence of hierarchical modulation, the α factor and the code rates for HP and LP are transmitted to the receiver in the TPS (Transmission Parameter Signaling) COFDM carriers [4].

3. Analysis of the Hierarchical Modulation in DVB-T/H

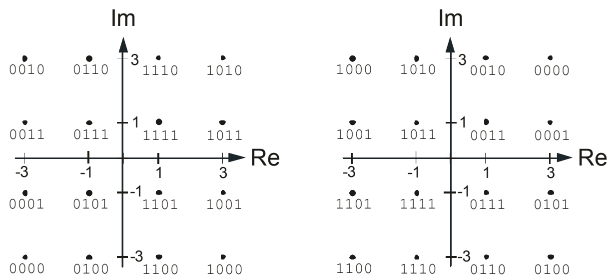
Each stream (HP and LP) is processed by separated FEC (Forward Error Correction) blocks, differentiating by different code rates [2]. Possible code rates of convolutional interleaver for LP stream are the same as in case of non-hierarchical modulation - 1/2, 2/3, 3/4, 4/5, 5/6 and 7/8. For HP stream, code rate of 1/2, 2/3 and 3/4 (just the most robust ones) [4] can be used. Both streams are joined together in the inner interleaver. Symbols consisting of v bits ($v = 4$ for 16-QAM and $v = 6$ for 64-QAM) are created using the first two bits from the HP stream and remaining bits (2 when using 16-QAM and 4 when using 64-QAM) are taken from the LP stream. The resulting stream is further processed as in case of non-hierarchical modulation.

Symbols are mapped into constellations that the first two bits of symbol in one quadrant are the same. So when the signal is impaired by heavy noise and higher modulation, quadrants can be still distinguished and HP stream can be still decoded, like it was modulated with QPSK modulation.

The non-uniform constellations have quadrants spread apart. Factor α (constellation ratio) determines the ratio between the spacing of two adjacent constellation points of two neighboring quadrants and can have value of α = 2, 4 (in case of uniform constellation α = 1). An increase of α leads to an increase of the average transmission power, but also to a decrease of required C/N ratio for HP stream. On the other hand, an increase of α also leads to an increase of LP stream C/N requirements [3].

4. Simulation of the Hierarchical Modulation in DVB-T/H

Hierarchical modulation using non-uniform constellations can not be directly simulated with Matlab in-built functions, as it does only support plain M-QAM modulation. There are two options that can be used to achieve properly mapped uniform and non-uniform constellations used by hierarchical modulation technique.



a) b)

Fig. 2. Gray mapping of individual bits to the 16-QAM constellation in a) Matlab, b) DVB-T/H.

The first way of creating QAM modulated symbols according to the DVB-T specification [4] is to assign values of the real (I) and imaginary (Q) part of the modulated symbol directly to the input symbols. However, this way of implementation is slow, as the cycle including assigning conditions has to be performed for each input symbol and there is a large amount of symbols processed in each simulation step.

The second way is based on adjustment of existing M-QAM modulation algorithm from Communication Toolbox. Function `modem.qammod(M)` creates M-QAM modulator object, that can be used with function `modulate` from Signal Processing Toolbox. Property `SymbolOrder` of the modulator object determines order in which symbols will be mapped. The default value is `'binary'` so it could be changed to `'gray'` as DVB-T uses Gray mapping. However it was found, that even after changing this setting, the symbol order does not match the mapping in the DVB-T specification [4]. This problem is illustrated in Fig. 2 a) and b). This can be solved by setting symbol order property to `'user-defined'`. This allows change the modulator property `SymbolMapping`, in which decimal symbol values are stored, when read column wise, starting in the left upper corner of the constellation diagram. For example, to properly map 16-QAM constellation in Fig. 2 b) it has to be defined: `SymbolMapping = [8 9 13 12 10 11 15 14 2 3 7 6 0 1 5 4]`. The final code performing symbol mapping and modulation for hierarchical or non-hierarchical modulation (mapping has no influence on the transmission or error rate in this case) is given below:

```
%prepare modulator objects according to modulation
switch settings.modulation
    % QPSK mapping
   case 'QPSK'
        modulator = modem.qammod(4);
        modulator.SymbolOrder =  ('user-defined');
        modulator.SymbolMapping = [2 3 0 1];
    % 16-QAM mapping
    case '16-QAM'
        modulator = modem.qammod(16);
        modulator.SymbolOrder =  ('user-defined');
        modulator.SymbolMapping = [8 9 13 12 10 11 15 14 ...
                                   2 3 7 6 0 1 5 4];
    % 16-QAM mapping
    case '64-QAM'
        modulator = modem.qammod(64);
        modulator.SymbolOrder =  ('user-defined');
        modulator.SymbolMapping = [32 33 37 36 52 53 49 ...
                                   48 34 35 39 38 54 55 ...
                                   51 50 42 43 47 46 62 ...
                                   63 59 58 40 41 45 44 ...
                                   60 61 57 56 8 9 13 12 ...
                                   28 29 25 24 10 11 15 ...
                                   14 30 31 27 26 2 3 7 ...
                                   6 22 23 19 18 0 1 5 ...
                                   4 20 21 17 16];
end

% perform modulation
modulated = modulate(modulator, symbols);
```

Steps described above provide us properly mapped symbols into uniform M-QAM constellations. To map non-uniform constellations, complex values of mapped symbols have to be changed to spread the constellation quadrants apart. Values of *I* and *Q* parts of the complex symbols are stored in modulator property `Constellation`, however this property is read-only and can not be unlocked for user values like in case of `SymbolMapping` property. A simple yet fully functional solution was implemented. First, symbols are mapped into uniform constellations as described above. Then, constellation points are moved on the real axis, depending on the constellation ratio α

$$z_n = z_n - (\alpha - 1), \quad \mathrm{Re}\{z_n\} < 0$$
$$z_n = z_n + (\alpha - 1), \quad \mathrm{Re}\{z_n\} > 0 \tag{1}$$

next, constellation points are moved on the imaginary axis using the same rule

$$z_n = z_n - i(\alpha - 1), \quad \mathrm{Im}\{z_n\} < 0$$
$$z_n = z_n + i(\alpha - 1), \quad \mathrm{Im}\{z_n\} > 0 \tag{2}$$

The last step is to normalize the constellation power to assure that signal power will not change with the modulation scheme (it should also be done for uniform constellations). Matlab in-built function `modnorm` is used to obtain the scaling factor which the mapped signal is multiplied with. These steps are implemented in the following code:

```
% shift is alpha lowered by 1 (alpha 1=hierarchy, but
uniform)
shift = settings.hierarchy-1;
% hierarchical scaling - real part of signal
modulated(real(modulated)>0)=modulated(real(modulated)>0)+
shift;
modulated(real(modulated)<0)=modulated(real(modulated)<0)-
shift;

% hierarchical scaling - imaginary part of signal
modulated(imag(modulated)>0)=modulated(imag(modulated)>0)+j*
shift;
modulated(imag(modulated)<0)=modulated(imag(modulated)<0)-
j*shift;

% obtain scale
scale = modnorm(modulated, 'avpow', 1);
% normalize
modulated = modulated*scale;
% store scale
settings.scale = scale;
```

The obtained signal is ready for modulation on the RF carrier, using quadrature modulator [1], and its transmission through the channel can be simulated.

The carrier is demodulated and channel correction is performed as the first step on the receiver side. Since the pilot subcarriers, used for channel estimation, are generated by the same process as in case of uniform constellations, there is no difference between hierarchical and non-hierarchical transmission.

Next processing steps are exactly opposite to the modulator. The signal is divided by the scaling factor and opposite transformation to the (1) and (2) is applied to receive uniform, properly scaled constellation, which can be demodulated using standard Matlab demodulator. Demodulator object `modem.qamdemod(M)` is created using the same mapping settings as the previously described modulator and demodulation is performed by `demodulate` function.

One could notice that shifting constellation quadrants apart in the transmitter can cause problems when receiving heavily distorted signals and shifting quadrants back together on the receiver side. Constellation points that are closer than α-1 to the border of a quadrant, will be shift to the neighboring one. Tests of this technique proved that it is not an issue. Constellation points on such positions would already be improperly decoded, so their shift to the neighboring quadrant has no influence on the error rate.

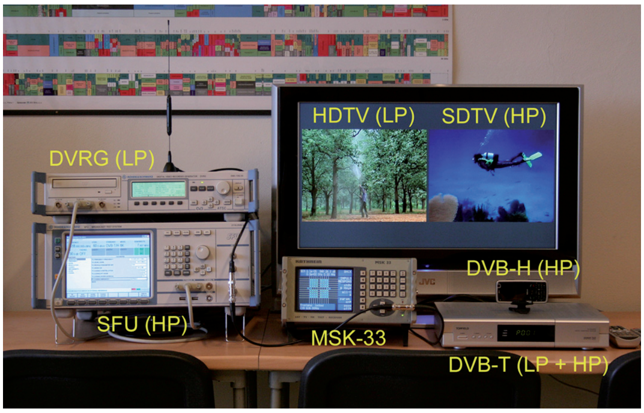


Fig. 3. Laboratory workplace for the DVB-T/H measurements and transmission link (SFU DVB-T/H test transmitter, SFU and DVRG MPEG-2 TS generators of HP and LP streams, MSK-33 DVB-T/H test receiver, DVB-T HDTV set-top box, DVB-H mobile phone, TVP set and screen with PAP function).

5. Measurement of the Hierarchical Modulation in DVB-T/H

Experimental testing of the hierarchical modulation used for DVB-T/H broadcasting with higher resolution in LP (fixed or portable reception) and DVB-T/H with lower resolution in HP (portable or mobile reception) was realized in the laboratory of digital television at the Department of Radio Electronics, Brno University of Technology.

The system parameters of the DVB-T/H signal for the hierarchical modulation and its performance evaluation were set to the configurations of the DVB-T/H in a large SFN considering fixed Digital TV reception (HDTV - High Definition TV - with MPEG-4 Part 10 service in LP stream) and with advanced option of the portable and mobile TV reception availability (SDTV - Standard Definition TV - or LDTV - Low Definition TV - with MPEG-2 MP@ML service in HP stream).

The DVB-T/H system transmission parameters were set to the European most common type of DTV broadcasting with extension to optional hierarchical modulation. These parameters are the most characteristic for the large DVB-T/H SFN networks:

- RF level 60 dBuV (medium sensitivity),
- 8 MHz channel (bandwidth 7.608 MHz),
- QPSK embedded in 64-QAM (TS 19.90588 Mbit/s),
- 8k mode – 6817 subcarriers (fit for fixed reception),
- 2/3 convolutional code (LP stream – less robust),
- 1/2 convolutional code (HP stream – more robust),
- 1/4 Guard Interval (large size SFN),
- hierarchical modulation $\alpha = 1, 2, 4$ (2x MPEG-2 TS).

For the measurement results, Gaussian (AWGN), Ricean (F1, RC20 ANX B), Rayleigh (P1, RL20 ANX B) channels profiles for fixed and portable reception of the DVB-T/H broadcasting [4] were used.

Hierarchical modulation performance and all the measurements were verified using DVB-T/H laboratory workplace (see Fig. 3). Test & Measurement devices that were used are:

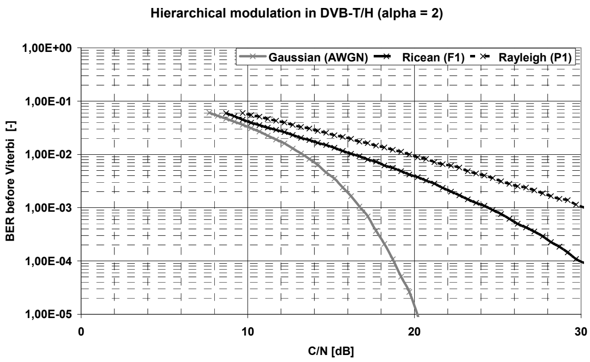
- R&S SFU DVB-T/H test transmitter
- R&S SFU MPEG-2 TS generator (HP stream),
- R&S DVRG MPEG-2 TS generator (LP stream),
- Kathrein MSK-33 DVB-T/H test receiver,
- STB Topfield TF7710 HTCI – DVB-T SDTV and HDTV set-top box
- Handheld Nokia N77 - DVB-H LDTV receiver and mobile phone,
- TVP LCD JVC TV set with PAP (Picture and Picture)

The influence of the variable parameter α on *MER*, BER_1 (before Viterbi) and BER_2 (after Viterbi) was evaluated for specific constellation diagrams to compare the simulation and measurements results.

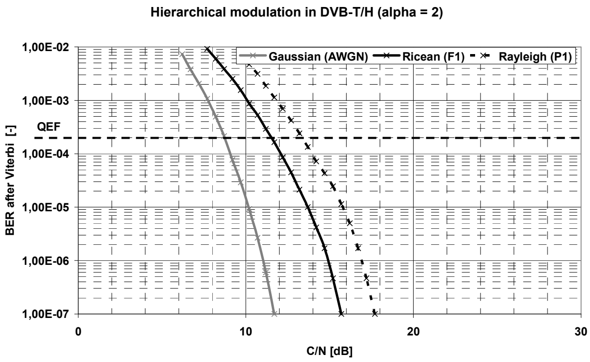
6. Experimental Results

The detailed results of the simulation and laboratory measurement of the *BER* before and after Viterbi decoding characteristics and *MER* (Modulation Error Ratio) from constellation analysis in dB for HP path and DVB-T/H service (used for portable or mobile reception) are available in Fig. 4 a) to c) and Fig. 5 a) to c).

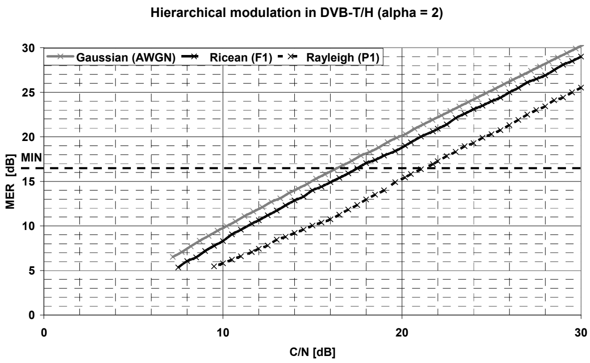
The “QEF” symbol in Fig. 4 b) and Fig. 5 b) indicates the situation where the *BER* after Viterbi decoding is equal to 2.10^{-4}. This was formerly defined condition of practically error-free signals at the input of the MPEG-2 TS demultiplexer. The “MIN” symbol in Fig. 4 c) and Fig. 5 c) indicates the situation where the DVB-T/H with modulation 64-QAM, convolutional code rate 2/3 and non-hierarchical modulation has the minimal required *CNR* equal to 16.5 dB [5]. This is the reference value of possible DVB-T/H in a no-interference reception. Hence, minimal value “MIN” of the *MER* in dB from constellation analysis was determined for the case of non-hierarchical modulation (64-QAM) to compare it with the hierarchical results (QPSK embedded in 64-QAM). From the characteristics of the *MER* it is easy to see hierarchical modulation advantage in the HP path with (9 – 13) dB of *C*/*N* needed in comparison with the non-hierarchical modulated 64-QAM with (18 – 23) dB for the MPEG-2 TS decoding. The difference between *MER* and *C*/*N* ratio in dB is equal to zero only in Gaussian (AWGN) channel, where all impairments are only by the mean of additive noise.



a) $BER_1 = f(C/N)$

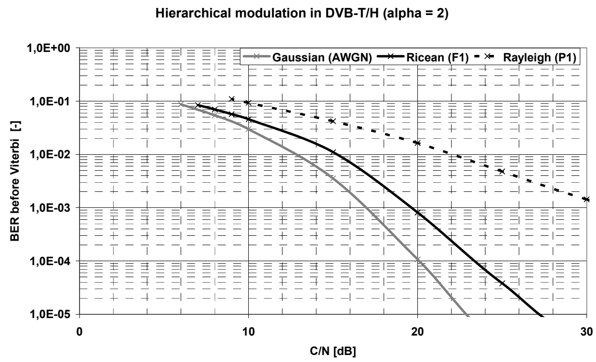


b) $BER_2 = f(C/N)$

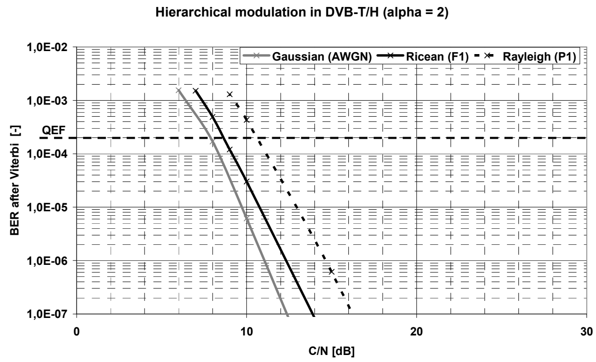


c) $MER = f(C/N)$

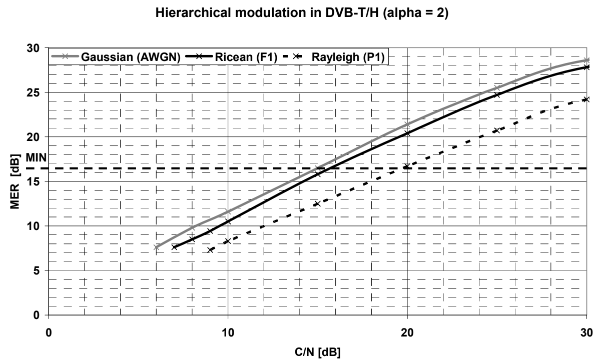
Fig. 4. Simulation: Hierarchical modulation performance in HP stream and various transmission channel type.



a) $BER_1 = f(C/N)$



b) $BER_2 = f(C/N)$

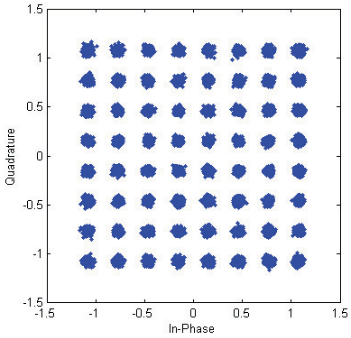


c) $MER = f(C/N)$

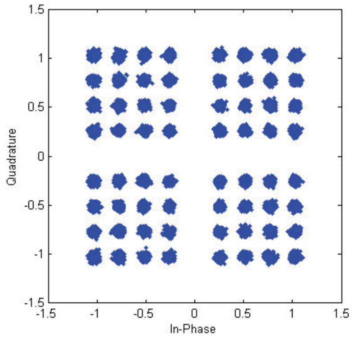
Fig. 5. Measurement: Hierarchical modulation performance in HP stream and various transmission channel type.

hierarchical modulation		simulation (only HP stream)			measurements (only HP stream)		
Channel	α [-]	BER_1 [-]	BER_2 [-]	MER [dB]	BER_1 [-]	BER_2 [-]	MER [dB]
Gaussian (AWGN)	1	$<1\cdot10^{-6}$	$<1\cdot10^{-6}$	30.2	$7.6\cdot10^{-6}$	$<1\cdot10^{-9}$	28.8
	2	$<1\cdot10^{-6}$	$<1\cdot10^{-6}$	30.2	$2.3\cdot10^{-6}$	$<1\cdot10^{-9}$	28.6
	4	$<1\cdot10^{-6}$	$<1\cdot10^{-6}$	30.1	$1.5\cdot10^{-6}$	$<1\cdot10^{-9}$	28.6
Ricean (F1)	1	$4.4\cdot10^{-4}$	$<1\cdot10^{-6}$	26.8	$3.9\cdot10^{-5}$	$<1\cdot10^{-9}$	28.1
	2	$1.4\cdot10^{-4}$	$<1\cdot10^{-6}$	26.8	$3.8\cdot10^{-6}$	$<1\cdot10^{-9}$	27.8
	4	$4.3\cdot10^{-5}$	$<1\cdot10^{-6}$	26.7	$1.1\cdot10^{-6}$	$<1\cdot10^{-9}$	27.8
Rayleigh (P1)	1	$3.2\cdot10^{-3}$	$<1\cdot10^{-6}$	22.3	$4.4\cdot10^{-3}$	$<1\cdot10^{-9}$	24.3
	2	$2.1\cdot10^{-2}$	$<1\cdot10^{-6}$	22.1	$1.4\cdot10^{-3}$	$<1\cdot10^{-9}$	24.2
	4	$2.1\cdot10^{-2}$	$<1\cdot10^{-6}$	22.1	$5.7\cdot10^{-4}$	$<1\cdot10^{-9}$	24.4

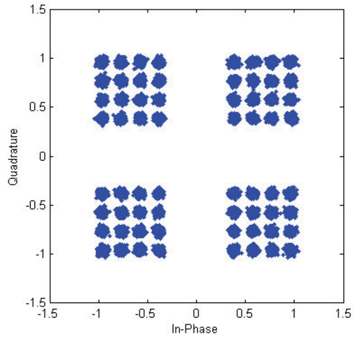
Tab. 1. Comparison of the simulation and measurement results for the DVB-T/H with QPSK embedded in 64-QAM, 8k mode, in case of hierarchical modulation and HP stream with C/N = 30 dB and standard channels - Gaussian (AWGN), Ricean (F1), Rayleigh (P1).



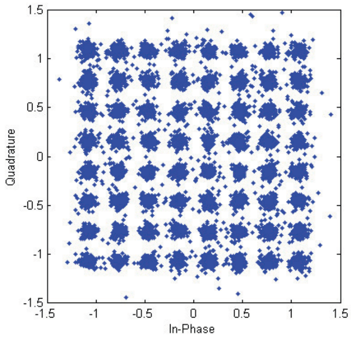
a) AWGN channel; α = 1;, MER = 30.2 dB;
HP: $BER_1 < 1\cdot10^{-6}$; $BER_2 < 1\cdot10^{-6}$
LP: $BER_1 < 1\cdot10^{-6}$; $BER_2 < 1\cdot10^{-6}$



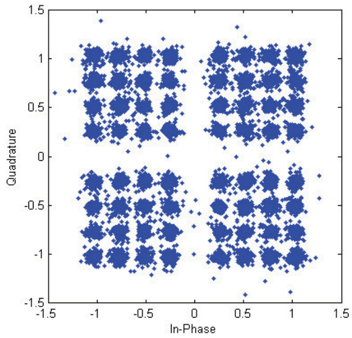
b) AWGN channel; α = 2; MER = 30.2 dB;
HP: $BER_1 < 1\cdot10^{-6}$; $BER_2 < 1\cdot10^{-6}$
LP: $BER_1 < 1\cdot10^{-6}$; $BER_2 < 1\cdot10^{-6}$



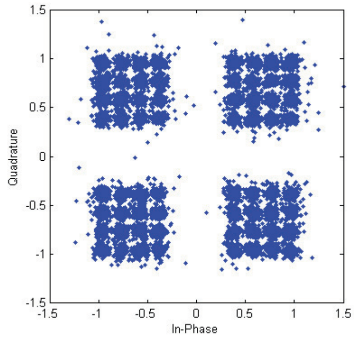
c) AWGN channel; α = 4; MER = 30.1 dB;
HP: $BER_1 < 1\cdot10^{-6}$; $BER_2 < 1\cdot10^{-6}$
LP: $BER_1 = 4.6\cdot10^{-6}$; $BER_2 < 1\cdot10^{-6}$



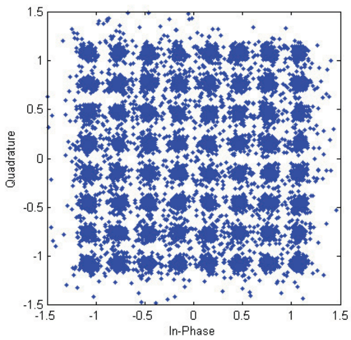
d) F1 channel; α = 1; MER = 26.8 dB;
HP: $BER_1 = 4.4\cdot10^{-4}$; $BER_2 < 1\cdot10^{-6}$
LP: $BER_1 = 1.4\cdot10^{-3}$; $BER_2 < 1\cdot10^{-6}$



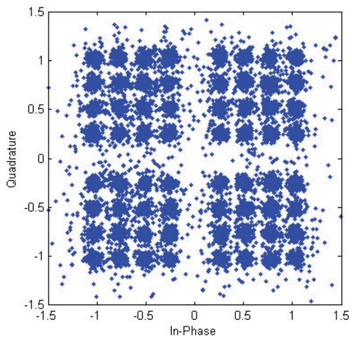
e) F1 channel; α = 2; MER = 26.8 dB;
HP: $BER_1 = 1.4\cdot10^{-4}$; $BER_2 < 1\cdot10^{-6}$
LP: $BER_1 = 2.1\cdot10^{-3}$; $BER_2 < 1\cdot10^{-6}$



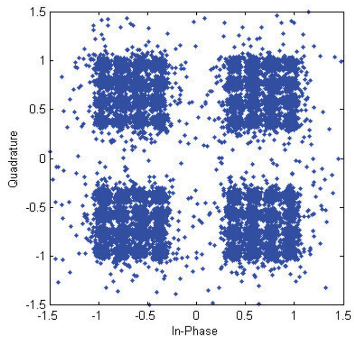
f) F1 channel; α = 4; MER = 26.7 dB;
HP: $BER_1 = 4.3\cdot10^{-5}$; $BER_2 < 1\cdot10^{-6}$
LP: $BER_1 = 4.8\cdot10^{-3}$; $BER_2 = 6.9\cdot10^{-6}$



g) P1 channel; α = 1; MER = 22.3 dB;
HP: $BER_1 = 3.2\cdot10^{-3}$; $BER_2 < 1\cdot10^{-6}$
LP: $BER_1 = 8.6\cdot10^{-3}$; $BER_2 = 2.5\cdot10^{-5}$



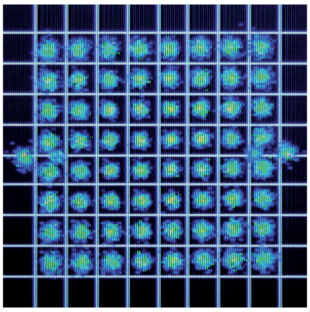
h) P1 channel; α = 2; MER = 22.1 dB;
HP: $BER_1 = 2.1\cdot10^{-2}$; $BER_2 < 1\cdot10^{-6}$
LP: $BER_1 = 1.1\cdot10^{-2}$; $BER_2 = 1.1\cdot10^{-4}$



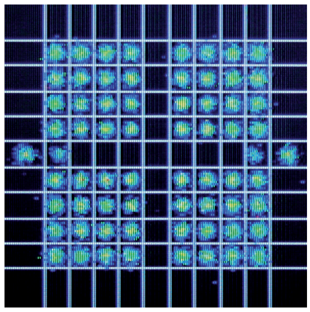
i) P1 channel; α = 4; MER = 22.1 dB;
HP: $BER_1 = 2.1\cdot10^{-2}$; $BER_2 < 1\cdot10^{-6}$
LP: $BER_1 = 1.6\cdot10^{-2}$; $BER_2 = 5.7\cdot10^{-4}$

Fig. 6. Simulation: I/Q constellation of the QPSK embedded in 64-QAM, 8k mode and in case of hierarchical modulation and standard DVB-T/H channels - Gaussian (AWGN), Ricean (F1), Rayleigh (P1) - (incl. channel correction but not pilots, C/N = 30 dB).

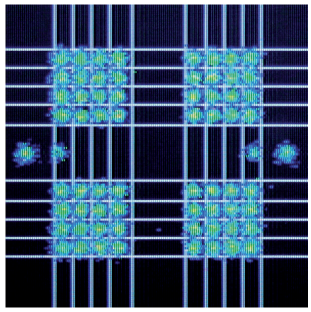
The main differences between simulation and the measurement results in the Fig. 4 and Fig. 5 are caused by low amount of the transmitted data within the simulation (approx. 150 kB). The difference in *BER* and *MER* results for the various channel type is also easy to compare in the Tab. 1 results. These results are comparison of the simulation and measurement and they are valid for the various channel type with the C/N = 30 dB. Typical results of the hierarchical modulated DVB-T/H and its constellation diagrams are depicted in Fig. 6 and Fig. 7.



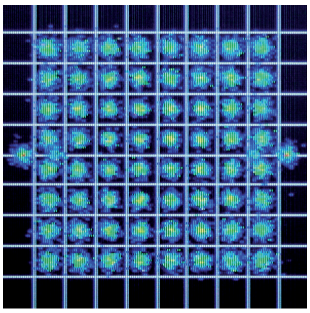
a) AWGN channel; $\alpha = 1$; MER = 28.8 dB;
HP: $BER_1 = 7.6 \cdot 10^{-6}$; $BER_2 < 1 \cdot 10^{-9}$
LP: N/A



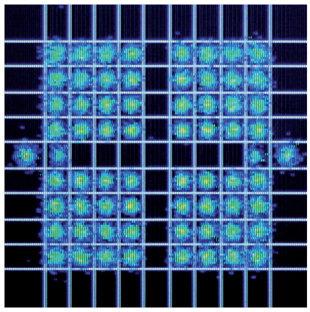
b) AWGN channel; $\alpha = 2$; MER = 28.6 dB;
HP: $BER_1 = 2.3 \cdot 10^{-6}$; $BER_2 < 1 \cdot 10^{-9}$
LP: N/A



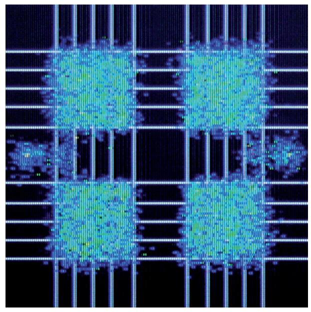
c) AWGN channel; $\alpha = 4$; MER = 28.6 dB;
HP: $BER_1 = 1.5 \cdot 10^{-6}$; $BER_2 < 1 \cdot 10^{-9}$
LP: N/A



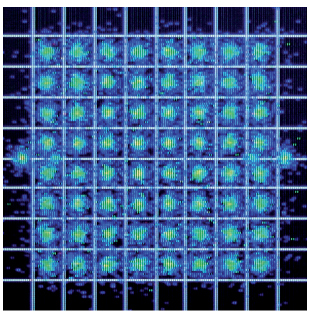
d) F1 channel; $\alpha = 1$; MER = 28.1 dB;
HP: $BER_1 = 3.9 \cdot 10^{-5}$; $BER_2 < 1 \cdot 10^{-9}$
LP: N/A



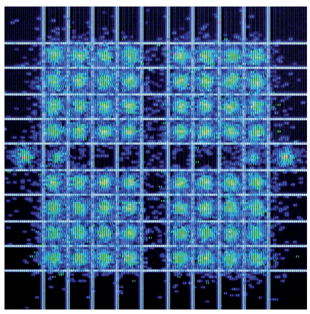
e) F1 channel; $\alpha = 2$; MER = 27.8 dB;
HP: $BER_1 = 3.8 \cdot 10^{-6}$; $BER_2 < 1 \cdot 10^{-9}$
LP: N/A



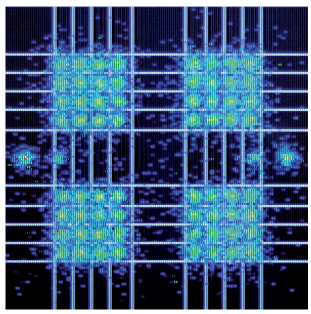
f) F1 channel; $\alpha = 4$; MER = 27.8 dB;
HP: $BER_1 = 1.1 \cdot 10^{-6}$; $BER_2 < 1 \cdot 10^{-9}$
LP: N/A



g) P1 channel; $\alpha = 1$; MER = 24.3 dB;
HP: $BER_1 = 4.4 \cdot 10^{-3}$; $BER_2 < 1 \cdot 10^{-9}$
LP: N/A



h) P1 channel; $\alpha = 2$; MER = 24.2 dB;
HP: $BER_1 = 1.4 \cdot 10^{-3}$; $BER_2 < 1 \cdot 10^{-9}$
LP: N/A



i) P1 channel; $\alpha = 4$; MER = 24.4 dB;
HP: $BER_1 = 5.7 \cdot 10^{-4}$; $BER_2 < 1 \cdot 10^{-9}$
LP: N/A

Fig. 7. Measurement: I/Q constellation of the QPSK embedded in 64-QAM, 8k mode and in case of hierarchical modulation and standard DVB-T/H channels - Gaussian (AWGN), Ricean (F1), Rayleigh (P1) - (incl. channel correction and pilots too, C/N = 30 dB).

From these constellation diagrams and of course from the example in the Fig. 1, the fact is evident that with the increasing parameter α from 1 to 4, there is need of an increase in *C*/*N* ratio in the transmission channel for the LP path availability and vice versa a decrease for the HP path availability. Good compromise in case of HM application is parameter $\alpha = 2$ where the requirements for the *C*/*N* for both paths are not marginal as it is easy to see from Fig. 1 b) or Fig. 7 b), e) and h). Also the results of such HM scenario were introduced in the Fig. 4 and Fig. 5.

7. Conclusion

The novelty of this paper is in evaluation of the hierarchical modulation performance in DVB-T/H standards. The results of the Matlab simulation (more details also in [7]) and laboratory measurements using set-top boxes and handhelds (more details also in [8]) were compared. The presented results can be used for DVB-T/H transmission distortions analysis and evaluation of the hierarchical modulation α parameters influence on fixed, portable and mobile reception of digital TV services.

Measured results of applied DVB-T/H hierarchical modulation in 8k mode (fixed and portable reception) and channels Ricean "F1" and Rayleigh "P1" show that LP and HP services are available at the same time and they are affected only with actual receiving conditions. In these channel models the Doppler shift was not introduced [4]. The simulation of the Ricean channel represents an approximation of the actual conditions when receiving signals via a rooftop antenna with high directivity (fixed reception, LP and HP paths available and possible HDTV service in LP stream). The Rayleigh channel is used to model the actual conditions when receiving signals via stationary receivers, which have a rod antenna (portable reception, low walking speed, only HP path available and possible SDTV or LDTV service in HP stream).

In case of hierarchical modulation it is necessary to supply details of the required *C*/*N* not only for the QPSK portion, but also for the M-QAM portion. According to [4] and [5], the theoretical demands for a minimum C/N fluctuate within a wide range from about 3.1 (4.9) dB for QPSK with a code rate 1/2 (2/3) in the Gaussian "AWGN" channel, cross 9.6 (11.6) dB for 16-QAM with a code rate 1/2 (2/3) in Ricean "F1" channel, up to 16.0 (19.3) dB for 64-QAM with a code rate of 1/2 (2/3) in the Rayleigh "P1" channel.

When comparing corresponding data of same code rates and case of non-hierarchical and hierarchical modulation for the mobile DVB-H, the *C*/*N* required for QEF reception of the HP data stream transmitted in QPSK constellation points must be higher than in the case of non-hierarchical modulation [9].

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References

[1] ŠTUKAVEC, R. KRATOCHVÍL, T. Simulation and measurement of the transmission distortions of the digital television DVB-T/H Part 1: Modulator for digital terrestrial television. *Radioengineering*, 2010, vol. 19, no. 2, pp. 338-346. ISSN: 1210-2512

[2] REIMERS, U. *Digital Video Broadcasting, The Family of International Standards for Digital Television.* 2nd ed. Springer, 2004. ISBN 3-540-43545-X.

[3] FISHER, W. *Digital Video and Audio Broadcasting. A Practical Engineering Guide.* 2nd ed. Springer, 2008. ISBN 978-3-540-76357-4.

[4] ETSI EN 300 744 V1.6.1 (2009-01). *Digital Video Broadcasting (DVB), Framing structure, channel coding and modulation for digital terrestrial television.* European Standard ETSI, 2009.

[5] ETSI TR 101 290 V1.2.1 (2001-05). *Digital Video Broadcasting (DVB), Measurement guidelines for DVB systems*. Technical Report ETSI, 2001.

[6] ETSI EN 302 304 V1.1.1 (2004-11). *Digital Video Broadcasting (DVB), Transmission system for handheld terminals*. European Standard ETSI, 2004.

[7] ŠTUKAVEC, R.; KRATOCHVÍL, T. Performance of hierarchical modulation in DVB-T. In *Proceedings of the 20th International Conference Radioelektronika 2010*. Brno (Czech Republic), 2010, pp. 49-52. ISBN: 978-1-4244-6319-0.

[8] KRATOCHVÍL, T.; ŠTUKAVEC, R. Hierarchical modulation in DVB-T/H mobile TV transmission over fading channels. In *Proceedings of the 2008 International Symposium on Information Theory and its Applications (ISITA2008).* Auckland (New Zealand), 2008, pp. 1-6. ISBN: 978-1-4244-2069-8.

[9] KRATOCHVÍL, T. Hierarchical modulation in DVB-T/H mobile TV transmission. In Plass, S., Dammann, A., Kaiser S., Fazel, K (eds.). *MultiCarrier Systems & Solutions 2009*. Lecture Notes in Electrical Engineering. Vol. 41. ISSN 1876-1100. Lecture Notes in Electrical Engineering. Herrsching, Germany: Springer Netherlands, 2009. pp. 334-341. ISBN: 978-90-481-2529-6.

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