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

Part 1: Modulator for Digital Terrestrial Television

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Abstract. *The paper deals with the first 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 modulator performance characteristics and its simulation and laboratory measurements are presented with focus on typical DVB-T/H broadcasting scenario – large SFN network for fixed reception. The paper deals with the COFDM modulator imperfections and I/Q errors influence on the DVB-T/H signals and the related I/Q constellation analysis. Impact of the modulator imperfections on Modulation Error Rate from I/Q constellation and Bit Error Rates before and after Viterbi decoding in DVB-T/H signal decoding are evaluated and discussed.*

Keywords

I/Q modulator, I/Q modulation error, Amplitude Imbalance, Phase Error, Carrier Suppression, COFDM, DVB-T/H.

1. Introduction

DVB-T/H (Digital Video Broadcasting – Terrestrial/ Handheld) [1] [2] are already classical ETSI standards [3]-[7] and technology for DTV (Digital Television) distribution. They are flexible systems that allow SFN networks (Single Frequency Network) to be designed for the delivery of a wide range of services, from LDTV (Low Definition), over SDTV (Standard Definition) to HDTV (High Definition). They both allow fixed, portable, mobile and even handheld reception.

Terrestrial transmission path is subject to numerous impacts such as echoes and multipath reception, AWGN (Additive White Gaussian Noise) and Doppler shift in case of mobile reception. Apart from this, the quality of the transmission link is also determined by the DVB-T/H modulator and transmitter parameters.

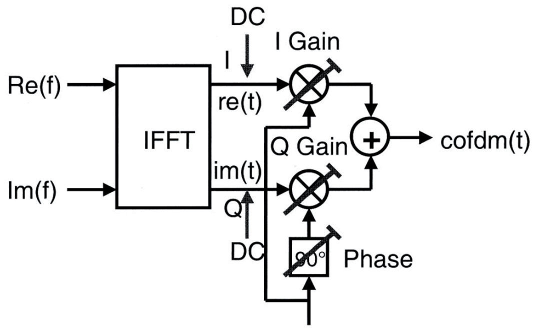


Fig. 1. DVB-T/H modulator with I/Q errors and imperfections (illustration comes from [2]).

A lower quality signal of the modulator can be produced by Crest factor limitation, intermodulation, noise, I/Q errors and interferers [1]. To avoid effects of the terrestrial transmission link and modulator imperfections, DVB-T/H use COFDM (Coded Orthogonal Frequency Division Multiplex). DVB-T/H modulator (see Fig. 1 or [2]) can exhibit imperfections caused by different gains in I/Q signals (Amplitude Imbalance), imprecise 90 degree phase shift between I and Q signals (Phase Error) or residual carrier in the frequency spectrum caused by DC component in I/Q signals (Carrier Suppression). Due to the channel estimation and carrier pilots all these effects result in lower *MER* (Modulation Error Rate) in dB from constellation analysis and according higher *BER* (Bit-Error Rate) before and after Viterbi decoding after the DVB-T/H signal decoding.

The Viterbi decoder can correct bit errors depending on the code rate selected in the convolutional encoder. The approximation condition for the QEF (Quasi-Error Free) reception, which corresponds to one error per hour, is defined as *BER* after Viterbi decoding equal to $2 \cdot 10^{-4}$ or less [3]. This is the limit at which the subsequent Reed-Solomon decoder delivers an output *BER* of $1 \cdot 10^{-11}$ or less. Slightly more noise or interference suffices and the DTV transmission breaks down (so called “cliff-off”).

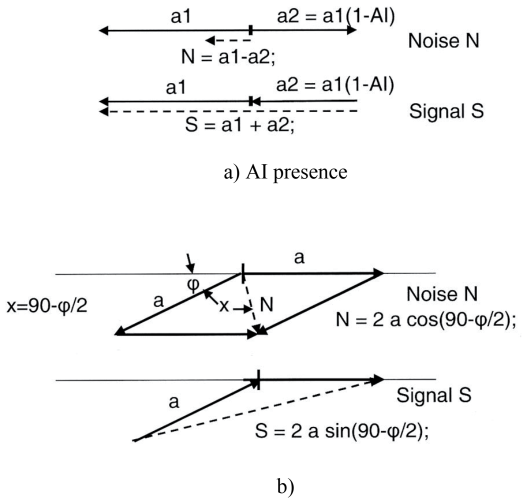


Fig. 2. Determining SNR by vector diagrams in case of I/Q errors: a) AI, b) PE (illustration comes from [2]).

2. Effect of I/Q Errors in DVB-T/H

The effects can be observed only at the center carrier. The other carriers exhibit noise like interference in the presence of any *AI* (Amplitude Imbalance) and *PE* (Phase Error).

While determining the *SNR* (Signal-to-Noise Ratio) with the *AI* and *PE* presence, equations (1) to (4) apply [2]:

$$SNR = \frac{a_1 + a_2}{a_1 - a_2} = \frac{2 - AI}{AI}, \quad (1)$$

$$SNR[dB] = 20\log\frac{2 - AI[\%]/100}{AI[\%]/100}, \quad (2)$$

$$SNR = \frac{2a}{2a} \cdot \frac{\sin\left(90 - \frac{\varphi}{2}\right)}{\cos\left(90 - \frac{\varphi}{2}\right)}, \quad (3)$$

$$SNR[dB] = 20\log\left(\tan\left(90 - \frac{\varphi}{2}\right)\right). \quad (4)$$

The disturbances in DVB-T/H caused by I/Q errors can be explained using vector diagrams (see Fig. 2). Both mixers of the DVB-T/H modulator operate with CS (Carrier Suppression) and SSB (Single Sideband Modulation) technique. Using this technique two sideband vectors are added and two sideband vectors are subtracted (cancelled band).

If the *AI* or *PE* exists means that the upper or lower sideband is no longer canceled completely and leaving an interference component. It is clear that all the subcarriers are subject to noise like interference, with the exception of the center carrier. It can be shown in the spectrum if the lower carrier band can be switched off. Hence, if the I/Q modulator is adjusted to produce *AI* or *PE*, an evident crosstalk from the upper to the lower sideband is clearly apparent (see example in Fig. 3).

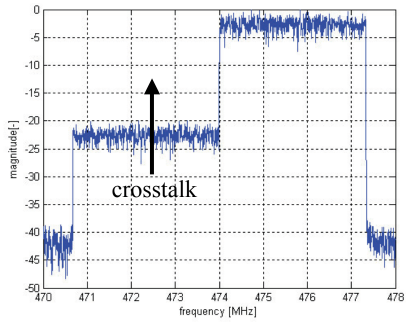


Fig. 3. Simulation: Spectrum of the DVB-T/H with 64-QAM, 8k mode and AI = 20%, PE = 10° (lower band of the carriers 0 - 3407 switched OFF in the modulator).

The DC component in *re*(*t*) or *im*(*t*) signals, after the IFFT, leads to a residual carrier in the I or Q branch or in both of them. Apart from the corresponding amplitude, the residual carrier also exhibits phase angle. A residual carrier at DVB-T/H modulator shifts the constellation diagram out of the centre in I or Q signal direction. The diagram remains undistorted and it can be verified only at the central carrier. Insufficient carrier suppression appears in the centre of the constellation diagram. Works related to this paper were also partly published in [8]-[10].

From the *SNR* or *MER* in dB, the *BER* before Viterbi decoding (channel *BER*) can be determined or at least estimated. Theoretical minimal *SNR* for QEF reception depends on the convolutional code rate, type of the COFDM inner modulation and type of the transmission channel – Gaussian, Ricean or Rayleigh [5].

Theoretical *CNR* (Carrier-to-Noise Ratio) value for the DVB-T/H signal transmission analyzed in this paper (64-QAM, 8k mode, 2/3 code rate, 1/4 guard interval, non-hierarchical modulation) is equal to 16.5 dB in the AWGN (Gaussian) channel for stationary reception. Practical *CNR* value is about 18 to 20 dB. The difference between *CNR* and *SNR* in DVB-T/H is 0.33 dB in 8k mode [2].

3. Analysis of the DVB-T/H Modulator and I/Q Imperfections

The system parameters of the DVB-T/H signal for the modulator imperfections and I/Q errors evaluation were set to the most common configurations of the DVB-T/H in a large SFN considering fixed Digital TV reception.

These parameters are DVB-T/H with 64-QAM modulation, COFDM 8k mode, convolutional code rate 2/3, guard interval 1/4 and non-hierarchical modulation.

For the *AI*, *PE* and *CS* influence on *MER*, BER_1 (before Viterbi) and BER_2 (after Viterbi) evaluation, the modulator parameters were set in these intervals:

- *AI* – Amplitude Imbalance (0 ... 25 % with step of 2 %),
- *PE* – Phase Error (0 ... 10^o with step of 1 degree),
- *CS* – Carrier Suppression (0 ... 50 % with step of 5 %).

4. Simulation of the DVB-T/H Modulator and I/Q Imperfections

The 8-bit input data with desired length is randomly generated. Forward Error Correction (FEC) is performed, as described in DVB-T/H specification. M-QAM modulation of useful data is performed and COFDM symbols are arranged in frequency domain, using useful data carriers and special ones, for transmission parameters signaling (TPS carriers), synchronization and channel estimation (continuous and scattered carriers) and ensuring proper channel spacing (zero carriers). Next, COFDM symbols are converted to the time domain using IFFT (Inverse Fast Fourier Transformation). Guard interval is inserted and baseband signal is upsampled and filtered with RRC (Root Raised Cosine) filter. Modulation on the carrier is performed. This is done by code below, following the structure of quadrature modulator in Fig. 1.

```
% separate input into I and Q branch
baseband_real = real(gray_mapped_upsampled);
baseband_imag = imag(gray_mapped_upsampled);
% prepare phase shift between I and Q carrier (radians)
phase = pi/180 * (90 + phase_error);
%generate I and Q carrier with modulator imperfection
carrier_real = cos(2*pi*fc*t)*(1+imbalance/200);
carrier_imag = cos(2*pi*fc*t+phase)*(1-imbalance/200);
% modulate I and Q branch separately
iq_modulated_real = baseband_real*carrier_real;
iq_modulated_imag = baseband_imag*carrier_imag;
% join I and Q branch together
iq_modulated = iq_modulated_real + iq_modulated_imag;
```

Here, `t` is a vector of discrete time samples and `fc` is carrier frequency. As can be seen from the code, amplitude imbalance and phase error of the modulator can be inserted. Phase error is in degrees, amplitude imbalance is in percent. One branch is amplified by half of the amplitude imbalance and second branch is attenuated by another half of the imbalance to maintain the average power. The quadrature demodulator is simulated the same way, just without errors

```
% 90 degree phase shift
phase = pi/180 * 90;
% generate I and Q carrier
carrier_real = cos(2*pi*fc*t);
carrier_imag = cos(2*pi*fc*t+phase);
% demodulate to the baseband
baseband_real = input.*carrier_real;
baseband_imag = input.*carrier_imag;
```

The MER is computed by comparing M-QAM modulated symbols (without noise) from transmitter and demodulated (noise and modulator errors impaired) signal from OFDM demodulator

```
% error vector
error_vector = OFDM_demodulated - MQAM_modulated;
% error RMS power
error_RMS = sum(abs(error_vector).^2)/length(error_vector);
% just for sure - 1 after normalization - signal RMS power
RMS = sum(abs(MQAM _modulated).^2)/length(MQAM_modulated);
% MER in decibels
MER_db = 10*log10(RMS/error_RMS);
```

Matlab in-built function was used to evaluate BER. BER before Viterbi decoding is computed by comparing output from convolutional coder on the transmitter side and output of inner deinterleaver on the receiver side. BER after Viterbi decoding is computed by comparing output of outer interleaver on the transmitter side with output of Viterbi decoder on the receiver side.

```
% BER before Viterbi decoding
[num_bit_before, BER_before] = biterr(inner_deinterleaved,
conv_encoded);
% BER after Viterbi decoding
[num_bit_after,B ER_after] = biterr(outer_interleaved,
viterbi_decoded);
```

It is obvious, that a large number of passband signal samples has to be processed. So, the maximal length of the input sequence is limited to 150 kilobytes (used for the simulations presented in this paper). This limitation does not allow us to evaluate BER smaller than $8.4 \cdot 10^{-7}$. However, lower BER values are not significant. As presented before, BER value of $2 \cdot 10^{-4}$ after Viterbi decoding results in 1 single error per hour (QEF) after all error corrections performed [3].

5. Measurement of the DVB-T/H Modulator and I/Q Imperfections

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

- RF level 60 dBuV (medium sensitivity),
- 8 MHz channel (bandwidth 7.608 MHz),
- 64-QAM modulation (TS 19.90588 Mbit/s),
- 8k mode – 6817 subcarriers (fixed reception),
- 2/3 convolutional code rate (robust code),
- 1/4 Guard Interval (large size SFN),
- non-hierarchical modulation (one TS).

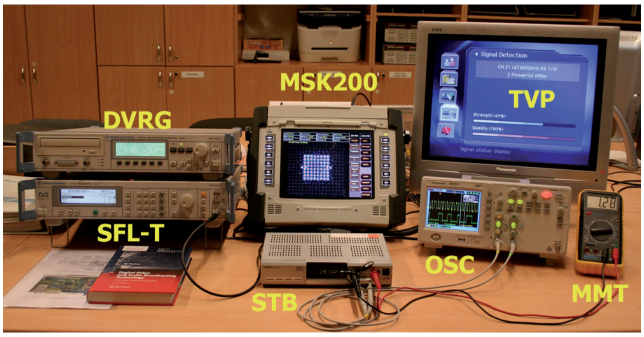


Fig. 4. Laboratory workplace for the DVB-T/H measurements and transmission link (SFL-T DVB-T/H test transmitter, DVRG MPEG-2 TS generator, MSK200 DVB-T/H test receiver, STB commercial set-top box added with tuner IF outputs and MPEG-2 TS data output, OSC digital oscilloscope, MMT multimeter, TVP TV set and screen).

I/Q errors and MER measurements were verified using DVB-T/H laboratory workplace (see Fig. 4). Test & Measurement devices that were used are:

- SFL-T R&S DVB-T/H test transmitter,
- DVRG R&S MPEG-2 TS generator,
- MSK200 Kathrein DVB-T/H test receiver,
- STB Humax F3 FOX-T commercial set-top box adapted with tuner IF and MPEG-2 TS data output,
- OSC Agilent digital storage oscilloscope,
- MMT Metex multimeter,
- TVP LCD Panasonic TV set.

A notice to verification and measurement results: I/Q errors of the DVB-T/H modulator partially affect all the carriers as noise-like disturbance (typical shape of clouds in the constellation) and can only be identified by observing the central carrier no. 3408 in COFDM 8k mode.

6. Experimental Results

A really interesting evaluation could be the dependence of *MER* simultaneously on *AI* and *PE* as shown in Fig. 5. With *AI* higher than approx. 20 % and *PE* higher than approx. 8 degrees, the DVB-T/H signal is not available for decoding (it causes very high *BER*).

The results of the *MER* evaluation in dB as the functions of the *AI*, *PE* and *CS* are shown in Fig. 6. Moderate influence of I/Q errors on *MER* has the Amplitude Imbalance. Decrease of 10 dB in *MER* is caused by *AI* of approx. 10 % between I/Q signals (see Fig. 6a). It is evident that the most serious impact on I/Q errors has the Phase Error. Decrease of 10 dB in *MER* is caused with *PE* of approx. 6 degrees between I/Q signals (see Fig. 6b). There is no real impact and influence of Carrier Suppression on I/Q errors (see Fig. 6c).

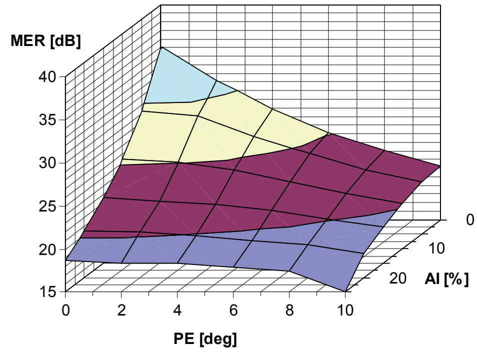
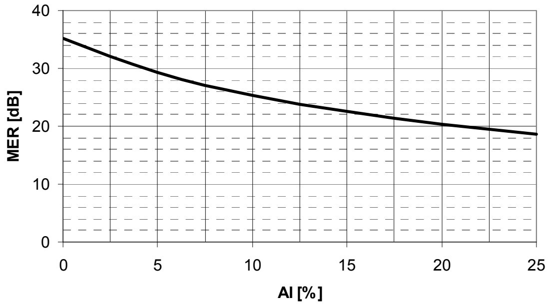
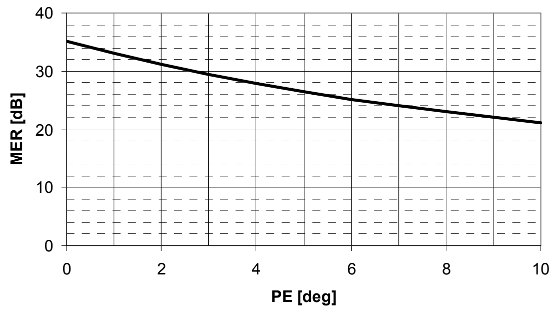


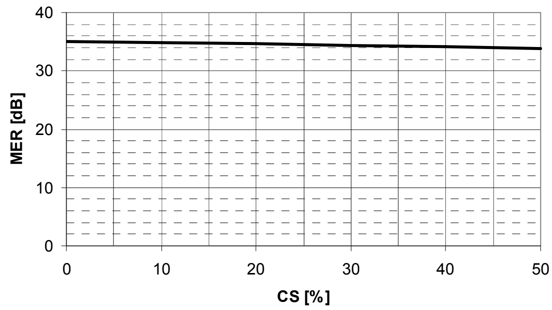
Fig. 5. Measurement: DVB-T/H modulator imperfections and I/Q errors influence on Modulation Error Ratio (MER). MER as a 2D function of the Amplitude Imbalance (AI) and Phase Error (PE) - MER = f(AI, PE).



a) $MER = f(AI)$

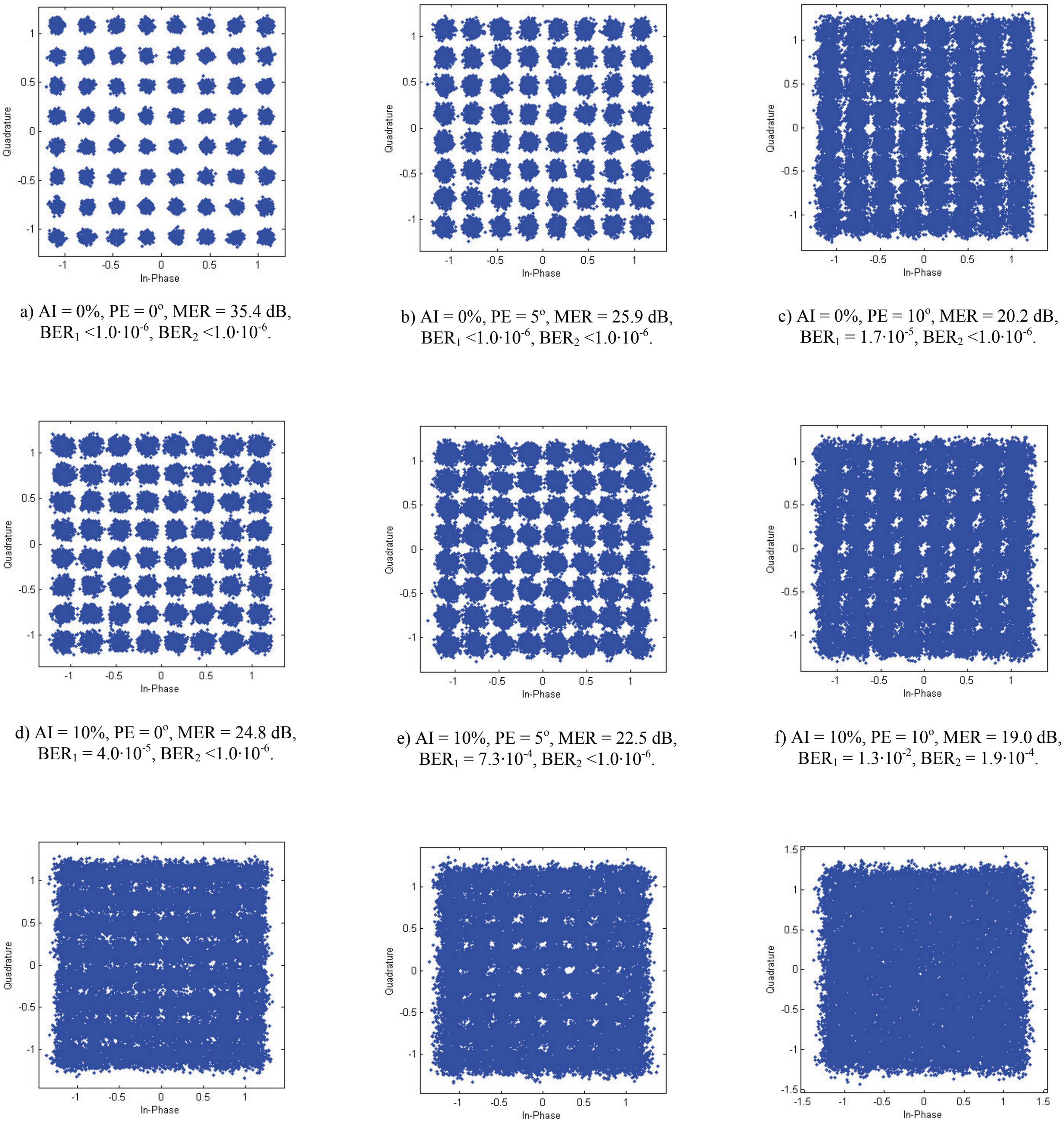


b) $MER = f(PE)$



c) $MER = f(CS)$

Fig. 6. Measurement: DVB-T/H modulator imperfections and I/Q errors influence on Modulation Error Ratio (MER). MER as a function of the a) Amplitude Imbalance (AI), b) Phase Error (PE), c) Carrier Suppression (CS).



a) AI = 0%, PE = 0°, MER = 35.4 dB, $BER_1 < 1.0 \cdot 10^{-6}$, $BER_2 < 1.0 \cdot 10^{-6}$.

b) AI = 0%, PE = 5°, MER = 25.9 dB, $BER_1 < 1.0 \cdot 10^{-6}$, $BER_2 < 1.0 \cdot 10^{-6}$.

c) AI = 0%, PE = 10°, MER = 20.2 dB, $BER_1 = 1.7 \cdot 10^{-5}$, $BER_2 < 1.0 \cdot 10^{-6}$.

d) AI = 10%, PE = 0°, MER = 24.8 dB, $BER_1 = 4.0 \cdot 10^{-5}$, $BER_2 < 1.0 \cdot 10^{-6}$.

e) AI = 10%, PE = 5°, MER = 22.5 dB, $BER_1 = 7.3 \cdot 10^{-4}$, $BER_2 < 1.0 \cdot 10^{-6}$.

f) AI = 10%, PE = 10°, MER = 19.0 dB, $BER_1 = 1.3 \cdot 10^{-2}$, $BER_2 = 1.9 \cdot 10^{-4}$.

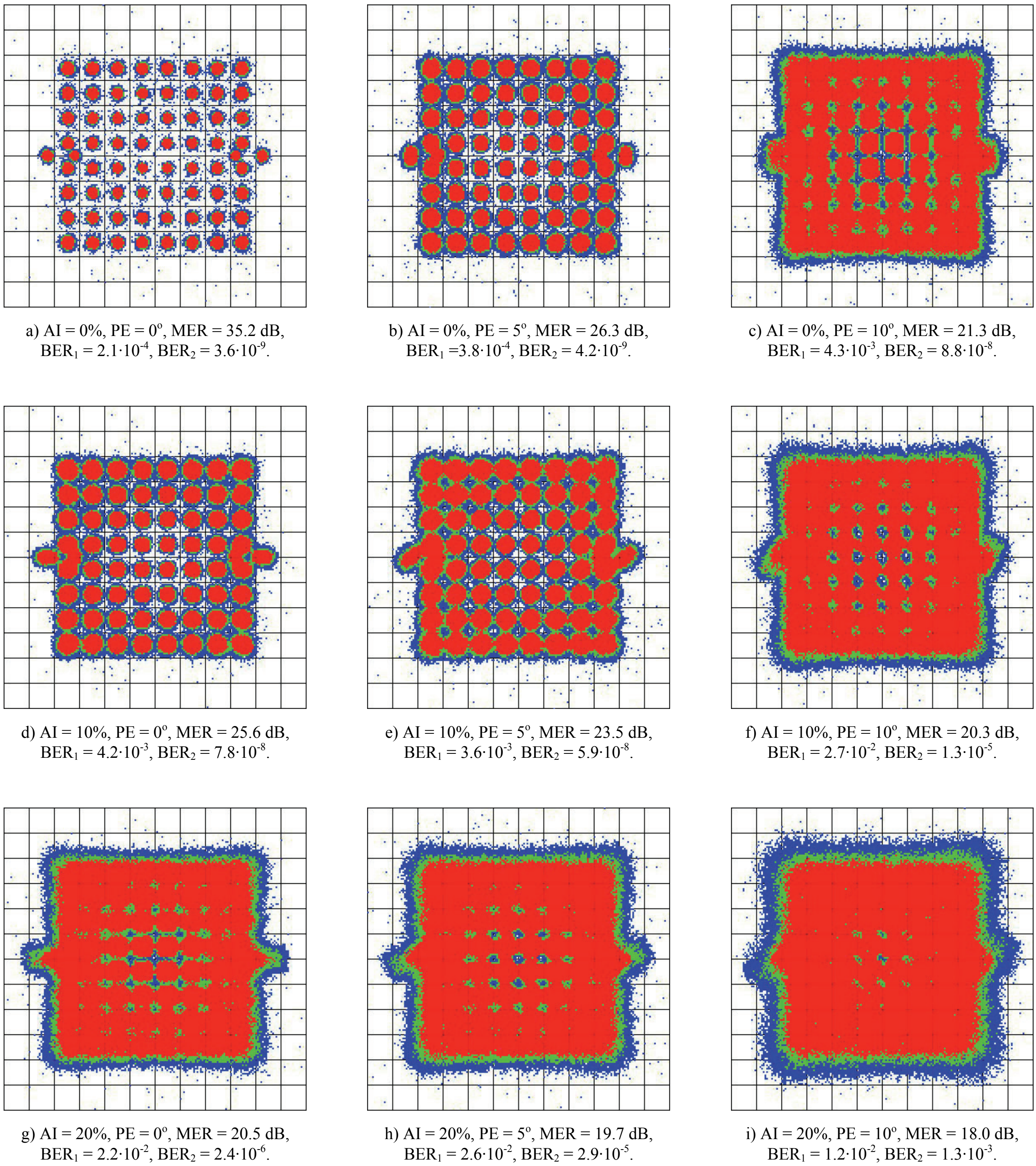
g) AI = 20%, PE = 0°, MER = 19.1 dB, $BER_1 = 1.1 \cdot 10^{-2}$, $BER_2 = 6.0 \cdot 10^{-5}$.

h) AI = 20%, PE = 5°, MER = 18.3 dB, $BER_1 = 1.9 \cdot 10^{-2}$, $BER_2 = 1.24 \cdot 10^{-3}$.

i) AI = 20%, PE = 10°, MER = 16.7 dB, $BER_1 = 4.3 \cdot 10^{-2}$, $BER_2 = 3.8 \cdot 10^{-2}$.

Fig. 7. Simulation: I/Q constellation of the 64-QAM, 8k mode and in case of AI and PE presence (incl. channel correction but not pilots).

The I/Q constellation diagrams for the simulation results are shown in Fig. 7a) to i) and the related constellations for the measurement results are in Fig. 8a) to i). As it was noticed before, the I/Q errors of the DVB-T/H modulator partially affect all the carriers as noise-like disturbance and they produce typical shape of clouds in the constellation. This was verified by the simulation and the real measurements using the DVB-T/H test transmitter in the laboratory environment. The real influence of the I/Q errors only is identified by observing the central carrier no. 3408 in COFDM 8k mode (in this case a continual pilot). The crosstalk between the lower and upper bands produces 64-QAM constellations with very low amplitude of I and Q signals in all individual constellation points. During the simulation, when the noise-like disturbance and AWGN (Gaussian channel) influence on the I/Q signals can be eliminated, the shape of small 64-QAM constellation diagrams is easy to see.



a) AI = 0%, PE = 0°, MER = 35.2 dB, $BER_1 = 2.1\cdot10^{-4}$, $BER_2 = 3.6\cdot10^{-9}$.

b) AI = 0%, PE = 5°, MER = 26.3 dB, $BER_1 = 3.8\cdot10^{-4}$, $BER_2 = 4.2\cdot10^{-9}$.

c) AI = 0%, PE = 10°, MER = 21.3 dB, $BER_1 = 4.3\cdot10^{-3}$, $BER_2 = 8.8\cdot10^{-8}$.

d) AI = 10%, PE = 0°, MER = 25.6 dB, $BER_1 = 4.2\cdot10^{-3}$, $BER_2 = 7.8\cdot10^{-8}$.

e) AI = 10%, PE = 5°, MER = 23.5 dB, $BER_1 = 3.6\cdot10^{-3}$, $BER_2 = 5.9\cdot10^{-8}$.

f) AI = 10%, PE = 10°, MER = 20.3 dB, $BER_1 = 2.7\cdot10^{-2}$, $BER_2 = 1.3\cdot10^{-5}$.

g) AI = 20%, PE = 0°, MER = 20.5 dB, $BER_1 = 2.2\cdot10^{-2}$, $BER_2 = 2.4\cdot10^{-6}$.

h) AI = 20%, PE = 5°, MER = 19.7 dB, $BER_1 = 2.6\cdot10^{-2}$, $BER_2 = 2.9\cdot10^{-5}$.

i) AI = 20%, PE = 10°, MER = 18.0 dB, $BER_1 = 1.2\cdot10^{-2}$, $BER_2 = 1.3\cdot10^{-3}$.

Fig. 8. Measurement: I/Q constellation of the 64-QAM, 8k mode and in case of AI and PE presence (incl. channel correction and pilots too).

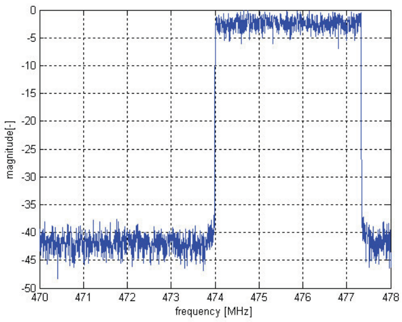
In the frequency spectrum of the DVB-T/H signal (see again example in Fig. 3), the crosstalk from the upper to lower band (and vice versa if both bands are ON during the modulation) in the DVB-T/H spectrum, is more visible with the increase of *AI* and *PE* presence.

To be more specific, with the evaluation of the simulation / measurement: The *PE* of 5 degrees produces 13/8 dB, 10 degrees produce 18/13 dB, *AI* of 10 percent produces 18/10 dB and AI of 20 percent produces 20/16 dB crosstalk. Simultaneous I/Q errors of *PE* equal to 10 degrees and *AI* equal to 20 percent produces 20/18 dB crosstalk.

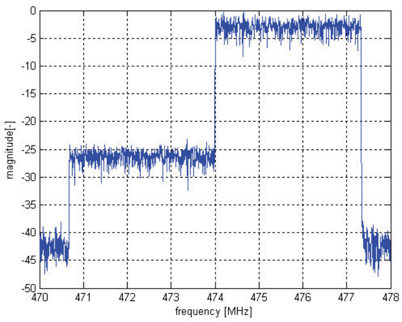
To conclude with the simulation/measurement results, the outcome of all I/Q interference effects on a DVB-T/H signal in broadband terrestrial SFN network is that the constellation points exhibit deviations with respect to their nominal positions in the center of the decision error and bit errors occur. Hence, the “cliff off” may happen.

I/Q errors		simulation			measurements		
AI [%]	PE [°]	BER_1 [-]	BER_2 [-]	MER [dB]	BER_1 [-]	BER_2 [-]	MER [dB]
0	0	$<1\cdot10^{-6}$	$<1\cdot10^{-6}$	35.4	$2.1\cdot10^{-4}$	$3.6\cdot10^{-9}$	35.2
0	5	$<1\cdot10^{-6}$	$<1\cdot10^{-6}$	25.9	$3.8\cdot10^{-4}$	$4.2\cdot10^{-9}$	25.4
0	10	$1.7\cdot10^{-5}$	$<1\cdot10^{-6}$	20.2	$4.3\cdot10^{-3}$	$8.8\cdot10^{-8}$	21.3
10	0	$4.0\cdot10^{-5}$	$<1\cdot10^{-6}$	24.8	$4.2\cdot10^{-3}$	$7.8\cdot10^{-8}$	25.6
10	5	$7.3\cdot10^{-4}$	$<1\cdot10^{-6}$	22.5	$3.6\cdot10^{-3}$	$5.9\cdot10^{-8}$	23.5
10	10	$1.3\cdot10^{-2}$	$1.9\cdot10^{-4}$	19.0	$2.7\cdot10^{-2}$	$1.3\cdot10^{-5}$	20.3
20	0	$1.1\cdot10^{-2}$	$6.0\cdot10^{-5}$	19.1	$2.2\cdot10^{-2}$	$2.4\cdot10^{-6}$	20.5
20	5	$1.9\cdot10^{-2}$	$1.2\cdot10^{-3}$	18.3	$2.6\cdot10^{-2}$	$2.9\cdot10^{-5}$	19.7
20	10	$4.3\cdot10^{-2}$	$3.8\cdot10^{-2}$	16.7	$1.2\cdot10^{-2}$	$1.3\cdot10^{-3}$	18.0

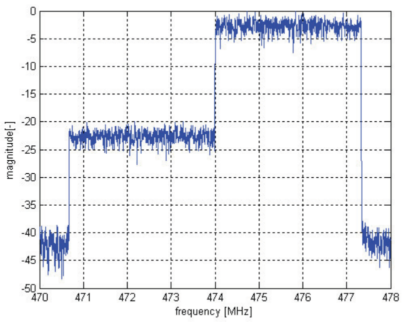
Tab. 1. Comparison of the simulation and measurement results for the DVB-T/H with 64-QAM, 8k mode and in case of AI and PE presence.



a) AI = 0%, PE = 0°

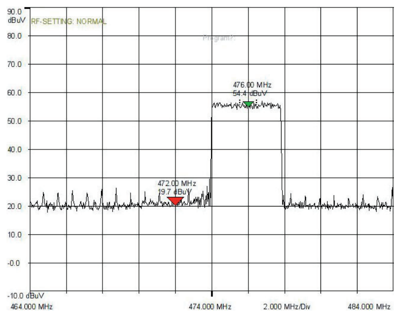


b) AI = 10%, PE = 5°

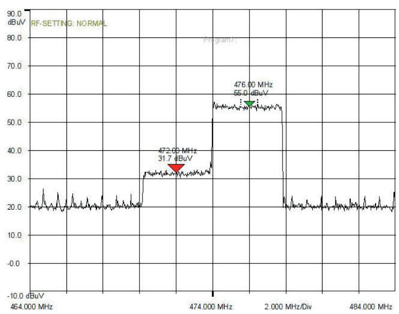


c) AI = 20%, PE = 10°

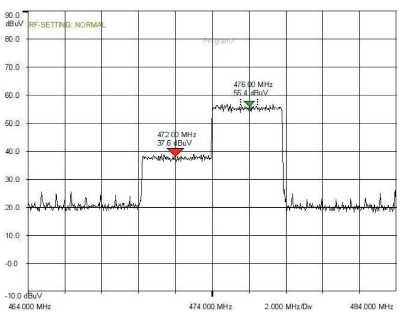
Fig. 9. Simulation: Spectrum of the DVB-T/H with 64-QAM, 8k mode and in case of the lower band of the carriers (0 – 3407) is switched OFF in the modulator.



a) AI = 0%, PE = 0°



b) AI = 10%, PE = 5°



c) AI = 20%, PE = 10°

Fig. 10. Measurement: Spectrum of the DVB-T/H with 64-QAM, 8k mode and in case of the lower band of the carriers (0 – 3407) is switched OFF in the modulator.

7. Conclusion

Novelty of this paper is in simultaneous evaluation of the *AI* and *PE* influence on the achieved results that is not often available and properly presented in the other scientific and technical papers. From the simulated and measured results it is easy to see that both the *AI* and *PE* lead to lower *MER* from the I/Q constellation analysis (see Tab. 1) and noise like crosstalk in the frequency spectrum (see Fig. 3 as an example).

The main differences between simulation and the measurement results in Tab. 1 are caused by low amount of the transmitted data within the simulation (approx. 150 kB) as introduced in Sec. 4. The difference in *BER* and *MER* results for the higher *AI* and *PE* is easy to see from Tab.°1.

The crosstalk from the upper band to lower band of the DVB-T/H spectrum is shown in the simulation (see Fig. 9) and measurements (see Fig. 10) results for the same situation of the *AI* and *PE* presence.

The effect of crosstalk can be described by means of simple trigonometric operations which can be derived from the vector diagram of the signal and noise. In the case of *AI* the opposite vectors of I/Q signals with noise are not cancelled completely, which results in a noise vector causing crosstalk from the upper band to lower frequency band. A phase error will result in a noise vector with its length determined by the vector parallelogram. In both cases the actual useful signal amplitude decreases by the same amount by which the crosstalk increases.

In the practical DVB-T/H modulator implementations usually *AI* less than 5 % and *PE* less than 0.5 degrees is the aim of the design and it is verified only very close to the center carrier (no. 3408 in case of the COFDM 8k mode). It is clear that all the subcarriers are subject to noise like interference, with the exception of the center carrier.

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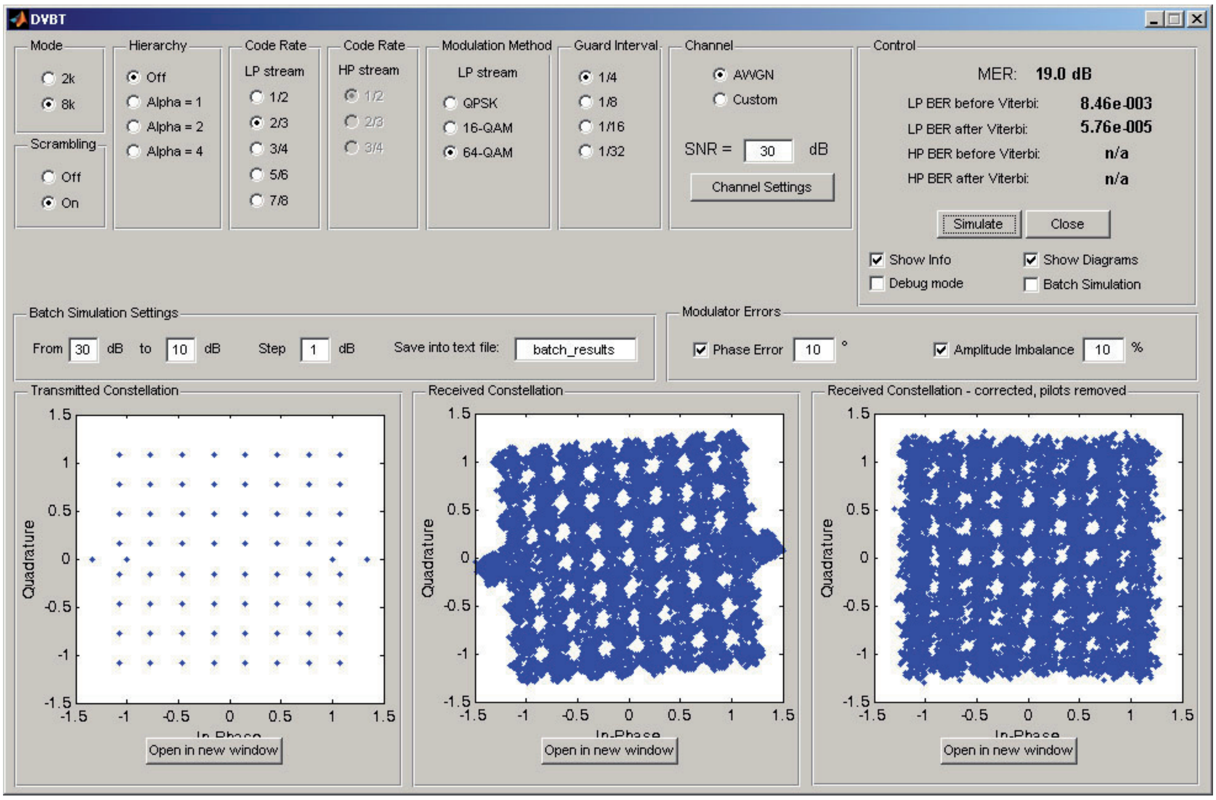

Fig. 9. Main window of the developed Matlab application "DVBT" for the interactive terrestrial DTV transmission analysis and simulation.

Appendix

Main window of the developed Matlab application called "DVBT" and used for the interactive simulation in the DVB-T analysis and simulation can be seen in Fig. 9.

The application is composed of several independent functional blocks. The structure of the transmitter basically follows the common DVB-T transmitter block diagram. Each block is represented by one m-file function. Where possible, block parameters can be set to the various transmission parameters defined by DVB-T specification [3]. The receiver is programmed as inverted transmitter, just channel estimation and channel correction blocks were added to correct multipath propagation influence on the received signal.

User can choose the type of the channel (Gaussian, Rice and Rayleigh) and set up to 20 independent paths of multipath propagation. The path settings are available in a separate window (after clicking on the "Channel settings" button). Gain and delay of each path can be set as defined in [5] or set individually by a user. The application is currently utilizing channel simulator function included in the Communication toolbox.

The noise ratio *C/N* (Carrier-to-Noise ratio) can be also set in the range of 5 to 50 dB. *BER* before and after Viterbi decoding is computed after successful simulation and output to the application window.

The "Show Info" option enables display of the current status of the simulation as well as each function processing time in the Matlab command line. The "Show Diagrams" option displays constellation diagrams of transmitted signal (left constellation), received signal (middle constellation) and received signal after channel correction (right constellation). The "Debug mode" can be turned on for application debugging purposes. Each processing step is stored into workspace variables, allowing evaluation of each block inner function process and its output results.

As the each run of the simulation is time consuming and a greater number of simulations has to be performed to construct a graphical representation of *BER* dependence on *C/N* ratio, the "Batch Simulation" option was implemented. The user can set start and end *C/N* ratio as well as the step. Results, including the settings used are stored in a user defined text file or Matlab workspace variable, as can be seen in Fig. 4.

As the last options the hierarchical modulation (also called layered modulation) technique and Modulator Errors were adopted recently. The application is developed within the framework of the main author's Ph.D. Thesis.

The application is available for free for scientific and non-commercial utilization after a kind request addressed by email to the authors of this article. A very simple licence agreement must be confirmed between the authors and the person who is requesting the "DVBT".