DVB-T MODULATOR IMPERFECTIONS EVALUATION AND MEASUREMENT

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Abstract: The paper deals with simulation, evaluation and measurement of the DVB-T modulator imperfections. Modulator imperfections' and I/Q errors' influence on the DVB-T signal and its spectrum and I/Q constellation analysis are presented. Theoretical backgrounds of the Amplitude Imbalance, Phase Error and Carrier Suppression effects are outlined in the paper. Then the practical results measured in the laboratory environment are compared to the theoretical assumed impacts on Modulation Error Rate from I/Q constellation and Bit Error Rates before and after Viterbi decoding in DVB-T signal decoding. Commented results of the measurements are presented in the paper as well.

1 INTRODUCTION

The DVB-T (Digital Video Broadcasting – Terrestrial) is already a standard (ETSI, 2004) and technology for Digital TV distribution.

Technical characteristics make the DVB-T system flexible to operate in a combination of

- 3 modulations (QPSK, 16-QAM, 64-QAM),
- 5 FEC rates (Forward Frror Correction),
- 4 Guard Intervals (1/32, 1/16, 1/8, 1/4),
- 3 modes of carriers - 2k (1705) or 8k (6817),
- 3 channel bandwidths (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.

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 modulator and transmitter parameters. A lower quality signal can be produced caused by Crest factor limitation, intermodulation, noise, I/Q errors and interferers (Fisher, 2008).

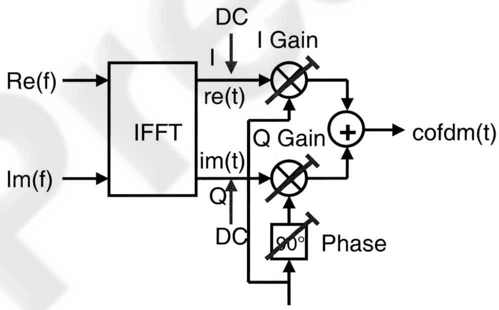

Figure 1: DVB-T modulator with I/Q errors and imperfections (Fisher, 2008).

To avoid effects of the transmission link and modulator imperfections, DVB-T uses COFDM (Coded Orthogonal Frequency Division Multiplex). DVB-T modulator (see Fig. 1) can exhibit imperfections caused by different gains in I/Q signals (Amplitude Imbalance), imprecise 90 degree phase shift between I/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 I/Q constellation and according higher *BER* (Bit-Error Rate) (ETSI, 2001).

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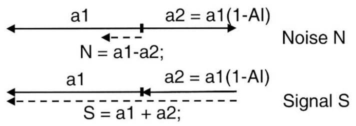
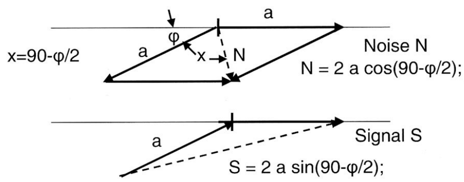
2 EFFECTS OF THE I/Q ERRORS

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).



a) AI presence



b) PE presence

Figure 2: Determining SNR by vector diagrams in case of I/Q errors (Fisher, 2008).

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

$$SNR = \frac{a_1 + a_2}{a_1 - a_2} = \frac{2 - AI}{AI}, \tag{1}$$

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

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

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

The disturbances in DVB-T caused by I/Q errors can be explained by using vector diagrams (see Fig. 2). Both mixers of the DVB-T 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, it means that the upper or lower sideband is no longer canceled completely and leaves an interference component.

It is clear that all the subcarriers are subject to noise like interference, with the exception of the center carrier. This can be shown in the spectrum if the lower carrier band is 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.

A 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 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.

Some works related to this paper were published also by (Bucholtz, 2000) and (Palipana, 2005, 2007).

3 BEHIND THE I/Q ERRORS

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 2.10^{-4} or less. This is the limit at which the subsequent Reed-Solomon decoder still delivers an output *BER* after RS decoding of 1.10^{-11} or less. This condition almost corresponds to the "fall of the cliff" and "blockiness" appearing in the picture. Slightly more noise or interference suffices for the DTV transmission to break down.

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 the type of the transmission channel - Gaussian, Ricean or Rayleigh (ETSI, 2001, 2004).

Theoretical *CNR* (Carrier-to-Noise Ratio) value for the DVB-T signal transmission analyzed in this paper (64-QAM, 8k mode, 2/3 code rate, 1/8 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 (Fisher, 2008).

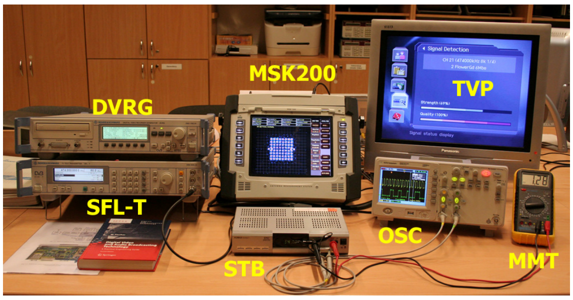


Figure 3: Laboratory workplace for the DVB-T measurements and transmission link.

4 DVB TRANSMISSION SYSTEM

Laboratory workplace for the DVB-T measurements (see Fig. 3) has been used for the evaluation of I/Q errors on *MER*. The devices are:

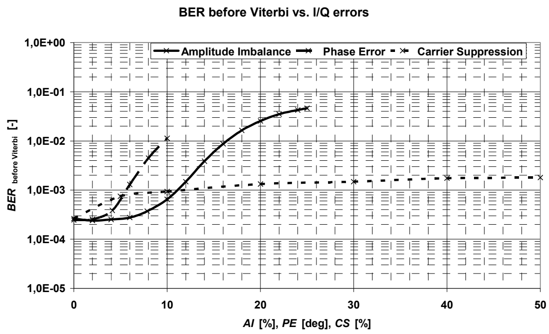
- SFL-T R&S DVB-T test transmitter,
- DVRG R&S MPEG-2 TS generator,
- MSK200 Kathrein DVB-T test receiver,
- STB Humax F3 FOX-T commercial set-top box adapted with tuner IF outputs and transport stream MPEG-2 TS data output,
- OSC Agilent digital storage oscilloscope,
- MMT Metex multimeter,
- TVP Panasonic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

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

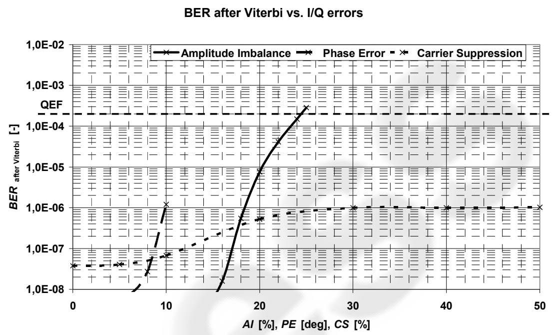
- RF level 60 dBuV (medium sensitivity),
- 8 MHz channel (bandwidth 7.608 MHz),
- 64-QAM modulation (TS 19.90588 Mbit/s),
- 8k mode – 6817 subcarriers (fixed reception),
- 2/3 convolutional code rate (robust code),
- 1/4 Guard Interval (large size SFN),
- non-hierarchical modulation (one TS).

For the Amplitude Imbalance *AI*, Phase Error *PE* and Carrier Suppression *CS* influence on *MER*, BER_1 (before Viterbi) and BER_2 (after Viterbi) evaluation, the DVB-T modulator and test transmitter parameters were set in these intervals:

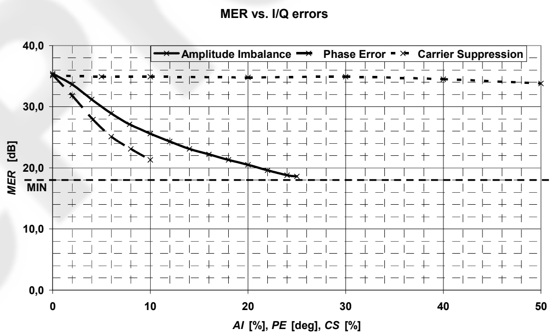
- AI - (0 .. 25% with step of 2%),
- PE - (0..10^o with step of 1 degree),
- CS - (0 .. 50% with step of 5%).



a) $BER_{\text{before Viterbi}} = f(AI, PE, CS)$



b) $BER_{\text{after Viterbi}} = f(AI, PE, CS)$



c) $MER = f(AI, PE, CS)$

Figure 4: DVB-T modulator imperfections and I/Q errors measurements (independent AI, PE and CS).

5 MEASUREMENT RESULTS

The results of the *BER* before Viterbi, *BER* after Viterbi and *MER* measurements as the functions of the *AI*, *PE*, *CS* are shown in Fig. 3. The “QEF” symbol in Fig. 4b) indicates the situation where *BER* after Viterbi decoding is equal to 2.10^{-4}. This is the formerly defined condition of practically error-free signals at the input of the MPEG-2 TS demultiplexer. The “MIN” symbol in Fig. 4c) indicates the situation where the DVB-T with modulation 64-QAM, convolutional code rate 2/3 and non-hierarchical modulation has the minimal required *CNR* equal to approx. 18 dB. This is the reference value of possible DVB-T in a no-interference reception.

The main impact on I/Q errors on *BER* and *MER* is caused by Amplitude Imbalance. Decrease of 10 dB in *MER* is caused by the *AI* of approx. 10 % between I/Q signals. It is evident that the most serious impact on I/Q errors has the Phase Error. Decrease of 10 dB in *MER* is caused by *PE* of approx. 6 degrees between I/Q signals. There is no serious impact and influence of Carrier Suppression on I/Q errors (see Fig. 5, all carriers displayed).

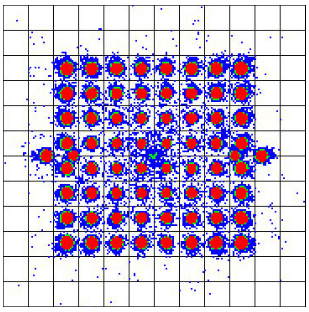


Figure 5: I/Q constellation of the DVB-T, 64-QAM, 8k mode and in case of CS = 50% presence (CS error visible in the centre of the diagram).

A really interesting evaluation could be the dependence of *AI* and *PE* simultaneously on *MER* as it is shown in the Fig. 6. With the *AI* higher than approx. 20 % and *PE* higher than approx. 8 degrees, the DVB-T signal is not available for decoding.

In Fig. 7, I/Q constellation diagrams of the DVB-T with 64-QAM, 8k mode are shown. In the individual pictures the simultaneous influence of AI and PE on the I/Q constellation is displayed. I/Q errors of the modulator partially affect all the carriers as noise-like disturbance (typical shape of clouds) and can only be identified by observing the central carrier (again no. 3408 in 8k mode).

6 CONCLUSIONS

From the measured results it is easy to see that both the *AI* and *PE* lead to lower *MER* from I/Q constellation analysis (see Fig. 7) and noise like crosstalk in the spectrum (see Fig. 8 and Fig. 9).

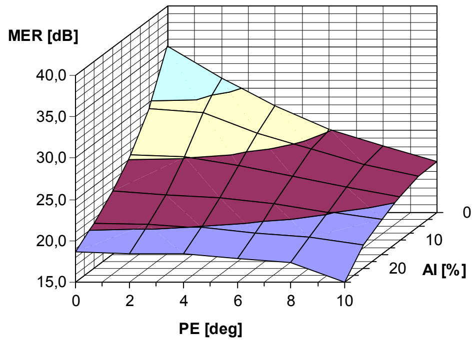
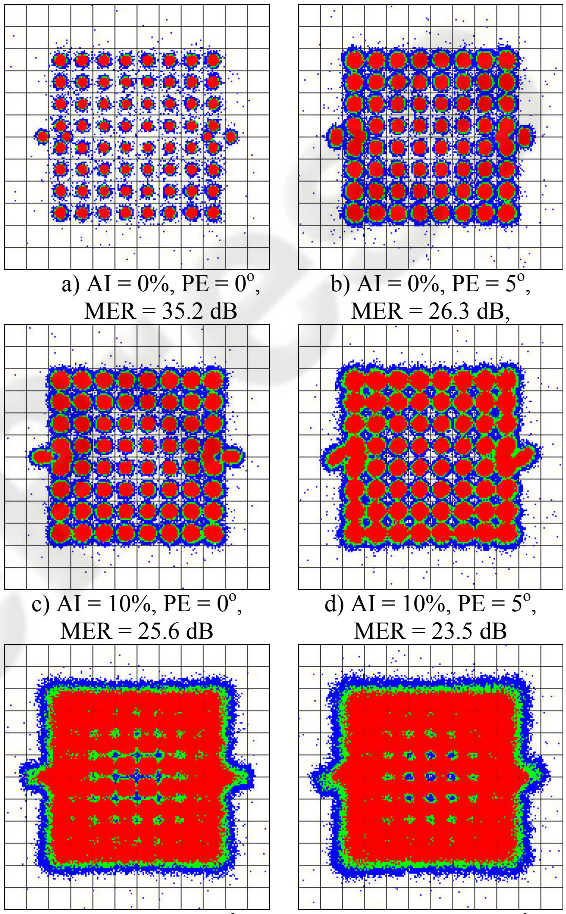


Figure 6: DVB-T modulator imperfections and I/Q errors measurements (simultaneous AI and PE).



a) AI = 0%, PE = 0^o, MER = 35.2 dB

b) AI = 0%, PE = 5^o, MER = 26.3 dB,

c) AI = 10%, PE = 0^o, MER = 25.6 dB

d) AI = 10%, PE = 5^o, MER = 23.5 dB

e) AI = 20%, PE = 0^o, MER = 20.5 dB,

f) AI = 20%, PE = 5^o, MER = 19.7 dB,

Figure 7: I/Q constellation of the DVB-T with 64-QAM, 8k mode and in case of AI and PE presence (DVB-T channel correction and all pilots ON).

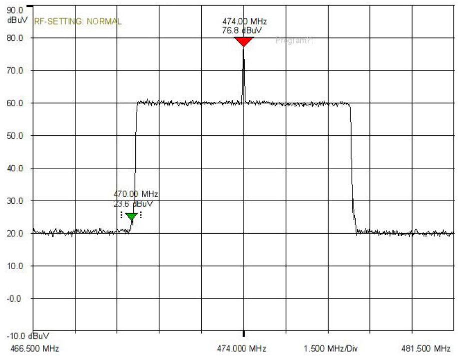
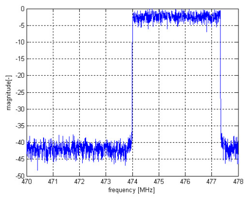
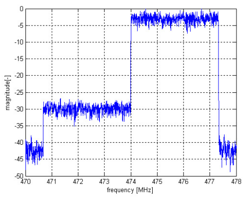


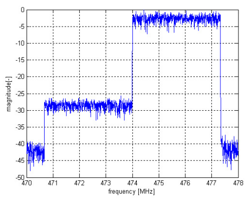
Figure 8: DVB-T spectrum without suppressed carrier, C21 (470 – 478) MHz, 8k mode, CS = 50% (CS error visible at central carrier, 474 MHz).



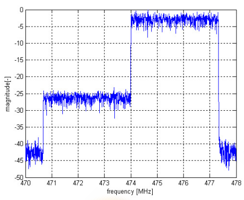
a) AI = 0%, PE = 0°



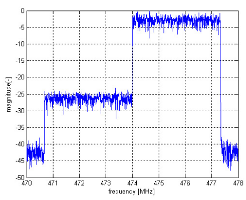
b) AI = 0%, PE = 5°



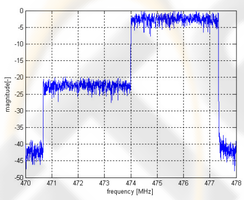
c) AI = 10%, PE = 0°



d) AI = 10%, PE = 5°



e) AI = 20%, PE = 0°



f) AI = 20%, PE = 5°

Figure 9: Simulated spectrum of the DVB-T with 64-QAM, 8k mode and in case of AI and PE presence (lower band carriers 0 - 3407 were set to zero to illustrate the crosstalk).

The effect 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 and it 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 the 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 and commercial DVB-T modulator implementations, usually *AI* less than 5% and *PE* less than 0.5 degree is the aim of the design and it is verified only very close to the center carrier (no. 3408 in case of the DVB-T and COFDM 8k mode) and adjacent carriers.

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