An Adaptive Equalizer to Reduce the Nonlinear Distortion Effects in Satellite Broadcasting Systems

Eduardo R. de Lima, André N. Sapper and Marcelo A. C. Fernandes

Abstract— **This article presents the BER performance improvements achieved when adopting Adaptive Equalization based on Decision Feedback Equalizer (DFE) to tackle the negative effects of nonlinear distortion in the receiver performance, caused by the Traveling Wave Tube Amplifier (TWTA), in a satellite receiver devoted to broadcasting. We have evaluated the performance for the DVB-S2 modulations, but the proposed DFE can be easily extended to be used in DVB-S2X systems. In our previous work we have presented the performance gains when using the same DFE to tackle the Inter-Symbol-Interference (ISI) caused by the Land Mobile Satellite Channel (LMSC). In that work, we have presented prototyping results in FPGA targeting a ASIC implementation. In this work we also investigate the performance improvements of the proposed DFE to tackle the effects of the nonlinearity combined with the ISI. The simulations results have shown that the proposed equalizer is capable of bringing significant performance improvements in both cases, i.e pure nonlinearity and nonlinearity combined with ISI, specially for the higher order modulation. It is worth mentioning that our proposal does not deal with the out-of-band spurious emissions caused by the nonlinear distortion, which needs to be handled by an appropriate technique such as predistortion.**

Keywords— **Adaptive Equalizer, DFE, Nonlinearities, ISI, DVB-S2, DVB-S2X, Satellite, Digital Television, Broadcasting.**

I. INTRODUCTION

In satellite systems, the effects caused by the nonlinearity of the TWTA and filter characteristics of an input de-multiplexer (IMUX) and an output multiplexer (OMUX) - which cause linear distortion [1] - are very critical to the system performance and shall be tackled [1], [2], [3]. A traditional way to deal with those effects is by means of pre-distortion techniques. Nevertheless, in [2], the authors have shown the potential of using a nonlinear Adaptive Equalizer, such as the DFE, to improve the receiver performance in the presence of those impairments. In this work we evaluate, by means of simulations, the performance enhancements of the Adaptive Equalizer, that we have proposed, implemented and presented in [5], can bring to a DVB-S2 [6] receiver in the presence of the nonlinear distortion caused by the TWTA. In addition, we evaluate the BER performance improvements the proposed scheme provides for the combination of LMSC and TWTA. It is worth to mention that the proposed equalizer can be easily extended to cope with the amendments provided by DVB-S2X [7].

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DVB-S2 can work in two modes regarding pilot structure, i.e. pilot and pilot-less modes. The pilot mode contains groups of pilots, embedded among data symbols, that are used by our equalizer as well as by other receiver algorithms [8]. In addition, DVB-S2 also provides a header that can be used as training sequence as well. So, the proposed equalizer architecture can make use of those embedded pilots and header as training sequence, as well as the data (for Decision Direct mode), and the radius of QPSK and 8-PSK and average radius of 16-APSK and 32-APSK modulations for the CMA (Constant Modulus Algorithm) [9] mode. The equalizer makes use of Least Mean Square (LMS) algorithm (see [10], [11]) for the adaptation of the DFE filters coefficients.

The remaining of the paper is organized as follows: Section II is devoted to provide a short overview on DVB-S2 standard and its amendment DVB-S2X. It also provides a view on the DVB-S2 frame structure, which is used by our equalizer. In Section III, the equalizer proposed in [5] is revisited. Section IV presents the simulation results for TWTA and LMSC. In Section V a related work and future works are discussed. Finally, we draw our conclusions.

II. DVB-S2 AND DVB-S2X

DVB-S2 is the state-of-art ETSI standard for satellite broadcasting [6]. It was developed by the Digital Video Broadcasting (DVB) project and the evolution of DVB-S. It takes advantage of Low Density Parity Check Code (LDPC) combined with Bose-Chaudhuri-Hocquenghem (BCH) code, to achieve near Shannon limit performance. Figure 1 shows the main blocks of a DVB-S2 transmitter and Figure 2 presents a simplified view of the DVB-S2 Physical Layer frame structure. The key characteristics that allows quasi-error free operation near (0.6 to 1.2 dB) Shannon limit are: 1) very large LDPC code block length (64800 bits for Normal Frame and 16200 bits for Short Frame); 2) large number of iterations on LDPC (around 50); and 3) the combination with BCH [8]. According to [6], [12], DVB-S2 has been designed for applications such as: broadcast for High Definition Television (HDTV), iterative services for consumer applications, Digital TV distribution and news gathering, distribution of signal to terrestrial transmitters, and others. It achieves about 30% of capacity gain over DVB-S, under the same transmission conditions. The standard has been specified around three key concepts: best transmission performance, total flexibility and reasonable receiver complexity. It supports Variable Coding Modulation (VCM), functionality that allows different modulation (QPSK, 8-PSK, 16-QAM and 32-QAM) and error protection levels

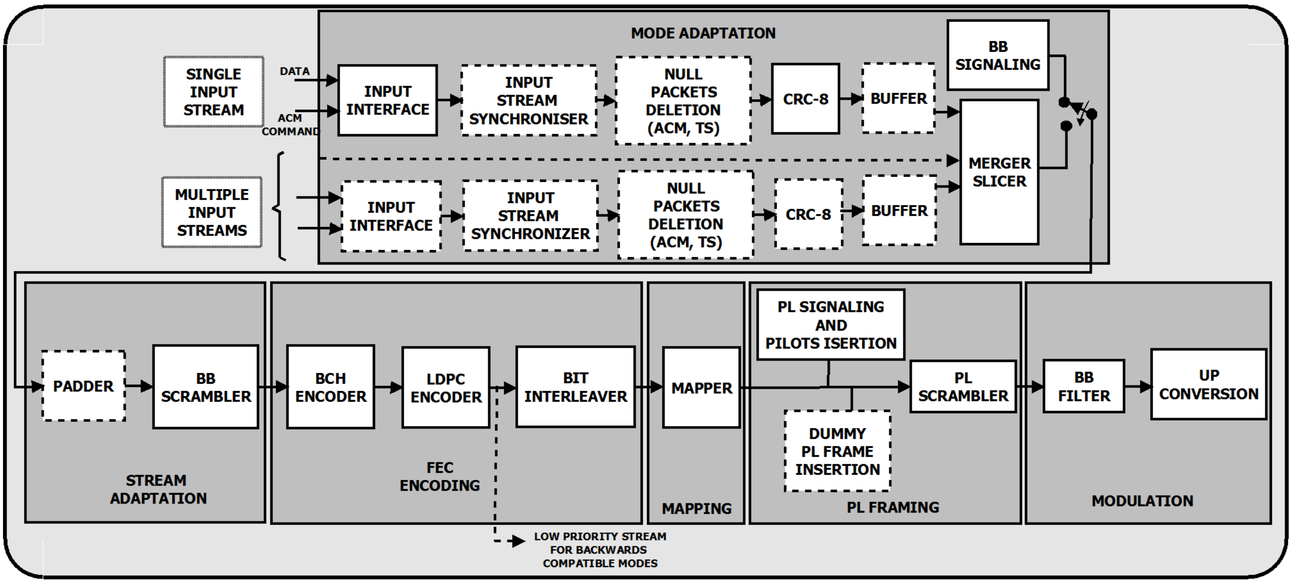

Fig. 1. DVB-S2 transmitter block diagram [6].

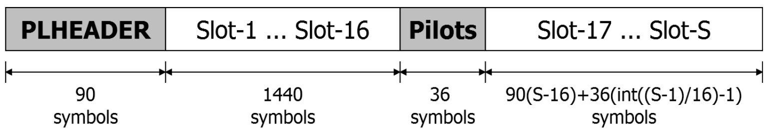

Fig. 2. DVB-S2 frame structure.

(1/4, 1/3, 2/5 ,1/2 , 3/5, 2/3) to be used on a frame by frame basis.

Despite DVB-S2 has been specified about 10 years ago and its advantages regarding DVB-S, it is still not widely used worldwide [8] (see also[13], [14]). Furthermore, most of the satellite links using DVB-S2 makes use of 8-PSK modulation. Therefore there is still room for the use of DVB-S2 standard and its current configuration options. Even though, in 2014, DVB-S2X [7], which is an amendment to DVB-S2, was released by ETSI. The main amendments to DVB-S2, according to [15] are:

- Extended operational range to cover emerging markets such as mobile applications;
- Support of C/N down to -10 dB for mobile applications;
- Roll-off options of 5% and 10%;
- New constellation options for linear and non-linear channels;
- A finer gradation and extension of number of modulation and coding modes;
- Additional scrambling options for critical co-channel interference situations;
- Channel bonding of up to 3 channels;
- Super-frame option.

An overview on DVB-S2X is provided in [4] and details on its frame structure and pilots can be found in [7]. It is worth mentioning that header and pilots of DVB-S2X besides can be used, for instance, for fine and coarse frequency error estimation and digital AGC, can also be used by an adapted version of the DFE proposed in this work to improve the DVB-S2X receiver performance in the presence of nonlinearities.

III. The Adaptive Equalizer Architecture

The Adaptive Equalizer proposed in [5], whose architecture is depicted in Figure 3, makes use of all elements of the DVB-S2 frame structure to compute the feed forward (FF) and feed backward (FB) DFE filters gains, i.e. it can use the Physical Layer Header (PLHEADER) as well as the Embedded Pilots as training sequence. Both elements are shown in Figure 2. In addition, the equalizer can make use of Decision Direct (DD) data for the DD mode and the constellation radius for QPSK and 8-PSK and average constellation radius for 16-APSK and 32-APSK in the case of CMA mode. It contains a mode switching engine, that in this study phase (i.e. before it be definitely adjust and integrated in the DVB-S2 receiver that is under development [8]), switches among modes using a heuristic fashion that has a switching mode threshold which is defined according to the convergence of the central tap.

The mode switch depends on two factors: the data type (i.e. pilot or payload data) that is being processed and the value of the central tap. As can be seen in Figure 2 a DVB-S2 frame contains a PLHEADER with 90 symbols and payload data symbols grouped in slots made of 90 symbols. Optionally, the frame can contain groups of 36 pilots embedded among groups of payload data slots, that can be used in the receiver synhcronization algorithms and as reference for the equalizer, when working in supervised training.

In our equalizer there exists four modes for the adaptation of the FF and FB filter coefficients: 1) without adaptation; 2) using embedded pilots and PLHEADER; 3) CMA and 4) DD. A typical switching operation can be described as: the DFE starts in training mode using PLHEADER. Next, during

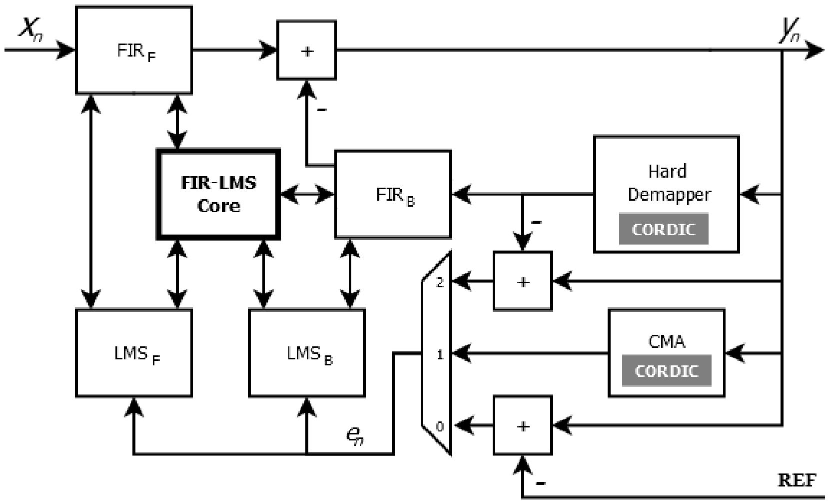

Fig. 3. The Adaptive Equalizer architecture proposed in [5].

the data payload, the equalizer uses CMA. If there exists embedded pilots they are used, otherwise the DFE keeps using the CMA until a threshold value for the central tap has been achieved.

The equalizer evaluated in this work contains a decision device based on the well known CORDIC (Coordinate Rotation Digital Computer) algorithm [16]. Further details about the CORDIC-based decision device can be found in [17]. The equalizer makes use of 16 taps in both filters (FF and FB) and the LMS algorihtm μ adopted for for FF and FB are respectively $1e-3$ and $1e-3$. Further study shall be done to define the optimal number of taps to reduce the implementation complexity of the equalizer. Refer to [5] for further details on the hardware architecture of the DFE used in this work.

IV. Simulations Performance

In this section we present several BER$\times$SNR curves, obtained through simulations using Octave and discuss the results. The IBO and OBO parameters used to obtain the simulations results shown in Figure 4 are presented in Table I. The channel used to obtain the simulations results presented in Figure 4 is shown in Table II. The Saleh model's IBO and OBO parameters, for moderate and severe nonlinear distortion presented in Table I were selected according to the Matlab's model for a DVB-S2 transceiver simulation using TWTA. Despite *low* nonlinear distortion was not used for the simulations presented in this work, the IBO and OBO values for this case are shown in Table I together with those parameters for *moderate* and *severe* cases.

To obtain the curves presented in this section, three parameters were used in a combined fashion: 1) the use or not of CMA; 2) the use of moderate or severe nonlinear distortion and 3) the use or not of ISI (in the case of LMSC). During the tests where CMA is not used, if the central tap target value is not reached, the gains update process is frozen until the DFE goes into supervised training mode, either by using PLHEADER or embedded pilots.

TABLE I

Input Back Off (IBO) and Output Back Off (OBO) parameters for the Saleh Model.

LOW	MODERATE	SEVERE
IBO		
-21.5957	1.40433	7.40433
OBO		
32.91183	9.91183	3.91183

TABLE II

Taps of the LMSC used for simulations.

LMSC TAPS
0.4577+0.0282i
0.1537+0.2213i
0.3578+0.4211i
0.2904+0.0980i
0.1966-0.2084i
-0.1530-0.2537i

It can be realized from the inspection of the BER curves presented in Figure 4 that, with exception of QPSK modulation and for moderate nonlinearity (see position top-left plot in Figure 4), all results present significant improvements in the performance when adopting the proposed DFE, in both cases, i.e. for TWTA and TWTA combined with ISI. The case of QPSK with moderate nonlinearity is still under investigation to discover the reason of the bad performance. Nevertheless, this does not disqualify the good results presented for the other cases.

V. Related and Future Work

In the best of the authors knowledge, the study of DFE to overcome nonlinear distortion in DVB-S2 systems using its ordinary payload symbols and pilots, was not found in the literature. Nevertheless, a study aiming at using DFE to overcome nonlinear distortion in advanced ISDB-S systems - that similarly to DVB-S2X has special pilots for that purpose

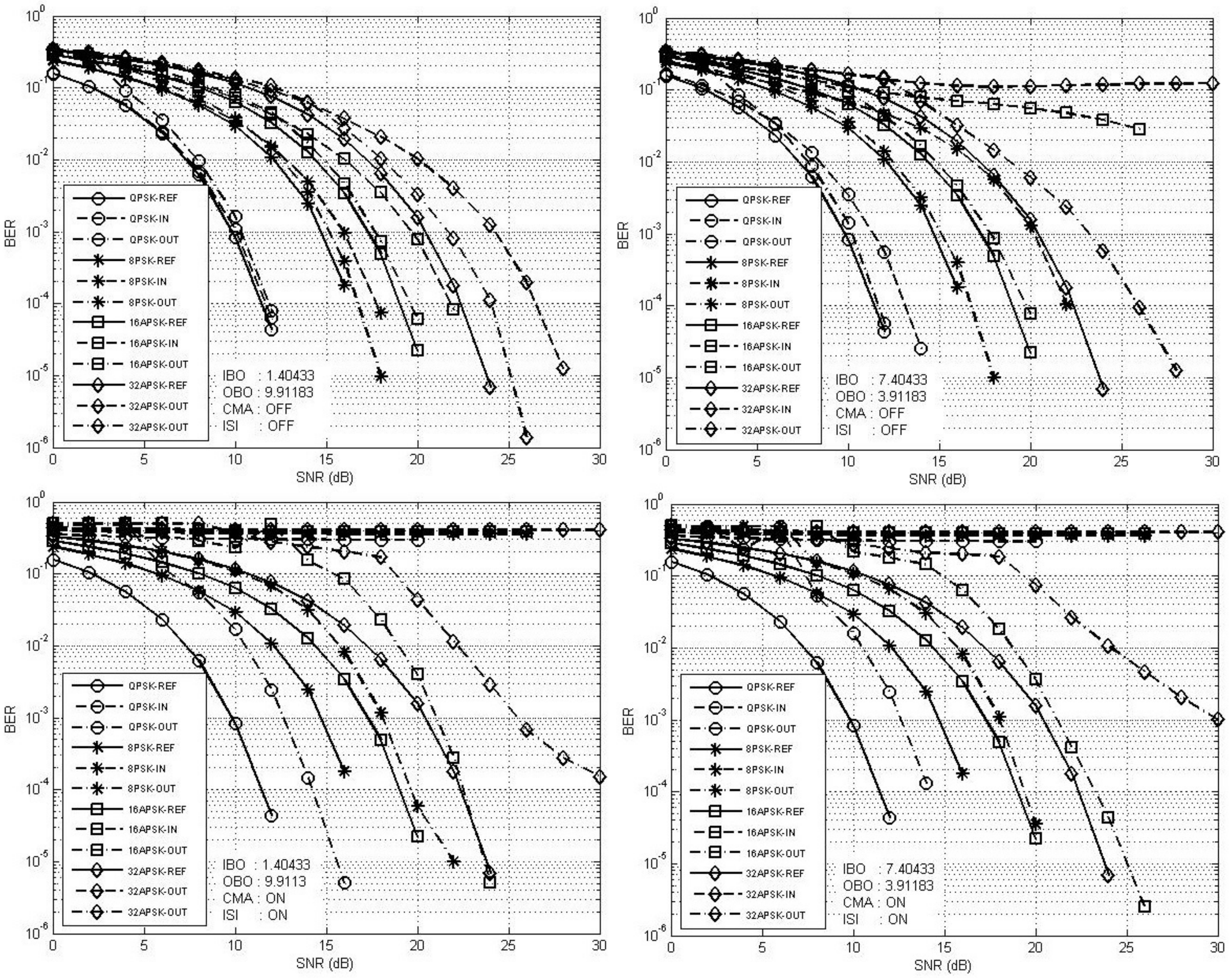

Fig. 4. BER performance for all DVB-S2 modulations (no interleaving and coding), in the presence of severe and moderate nonlinearity (using Saleh model), CMA "'on"' and "'off"', with and without ISI. The 6-tap static wireless channel, used in the simulations, was obtained by averaging 100 channel realizations using the Matlab embedded function "rayleighchan". All channel taps present Rayleigh statistics, modeling a complete non-line of sight LMSC.

- was performed in [2]. There, the authors also achieved performance gains when using such approach. Therefore, both studies confirm the validity of using DFE to overcome nonlinear distortion. Nevertheless, in the work present here, we do not make use of any special multilevel pilot, i.e. we make use of the original DVB-S2 pilots and symbols.

As future work we have several small tasks to perform, to explore the benefits of the proposal as well to explore parameters and scenarios to better characterize the equalizer and make it more robust to definitely be integrated in the DVB-S2 receiver [8] that is under development. Some of the tasks that shall be done are: the optimization of the number of taps of both filters (FF and FB), improvement in the switching mode heuristics, simulations using the DVB-S2 FEC susbystem, studies with different LMSC models, e.g. switching between Non-Line-Of-Sight (NLOS) and Line-Of-Sight (LOS) LMSCs to simulate the moving of a hypothetical user among two scenarios, and larger study with high speed mobility. Other possible future work, is to study the combination of pre-distortion techniques in conjunction with DFE, in order to improve the performance of receivers in the presence of nonlinear distortion.

VI. CONCLUSION

This work has shown by means of simulations that the DFE-based Adaptive Equalizer proposed by us in [5] can tackle the effects of the non linearity caused by the TWTA. Furthermore, it can handle the effects of ISI combined with TWTA nonlinearity. Despite the good results, further work must be done to refine the mode switch heuristic and to determine why when not using CMA the performance gains provide by the equalizer does not stand for QPSK in moderate nonlinear distortion scenario. Furthermore, as this work targets practical implementation in ASIC, refinements and optimizations shall be done to define the optimal number of taps for the FF and FB filters. It is worth mentioning that our proposal does not deal with the out-of-band spurious emissions caused by the nonlinear distortion, which needs to be handled by an appropriate technique such as predistortion.

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