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Digital pre-compensation technique to enhance predistortion performance in multicarrier DVB-S2 satellite communication systems

M. Allegue-Martínez, N. Kelly and A. Zhu

Nonlinearity in communication satellite payloads often severely degrades the downlink signal quality in such systems. This letter presents a digital pre-compensation technique to enhance digital predistortion performance in multicarrier satellite communication systems. The proposed technique has been validated by simulations with an appropriate platform where excellent performance improvements have been measured. In addition, implementation feasibility of this technique has been briefly demonstrated by means of a real-time FPGA implementation.

Introduction: With the increasing demands for higher channel capacity, bandwidth-efficient modulation schemes along with multicarrier operation will be widely deployed in satellite communications. In these systems, the information data is modulated on multiple carriers, which offer attractive flexibility and efficiency to satellite operators. However, signals with the former characteristics are particularly vulnerable to the nonlinear distortion introduced by the on-board High Power Amplifier (HPA), typically a travelling wave tube amplifier (TWTA).

Important advances have been achieved in channel linearization techniques in the last decade, particularly in the field of digital predistortion (DPD) [1]-[3]. Most reports in the literature are focused in the spectral regrowth elimination due to the presence of a nonlinear channel with less emphasis placed on the in-band pre-compensation, in contrast to [4, 5]. While the presence of input and output filters in transparent satellite payloads reduces the importance of out-of-band emissions, linear in-band performance remains critical in ensuring communication link quality. In this sense, some specific solutions have been proposed for satellite communications [6]. However, existing approaches are not suitable to multicarrier scenarios.

This letter proposes a pre-compensation technique to enhance digital predistortion performance by means of mitigating undesirable in-band linear effects in the satellite payload. These linear impairments severely degrade the performance of the communication system and prevent accurate identification of a nonlinear model needed to linearize the TWTA on the satellite. The linear impairments are introduced by two indispensable components in any satellite: the input de-multiplexing (IMUX) and output multiplexing (OMUX) filters. The technique proposed in this paper is suitable to be implemented immediately after an appropriate DPD block at the earth station to form a complete pre-compensation solution for multicarrier satellite transmissions.

Transparent satellite communication system: The scenario in which this technique is employed includes the following communication blocks: the earth station transmitter, the satellite payload and the receiver station also in earth as shown in Fig. 1. The transmitter possesses a digital baseband signal processing block for the generation of the uplink multicarrier signal and the implementation of the complete pre-compensation solution followed by the RF up-conversion block. The satellite payload is formed by the IMUX filter, the amplification system (TWTA) and then the OMUX filter. A conventional receiver station performs the down-conversion and the demodulation of the information contained in the corresponding carrier. The satellite payload has been modelled according to parameters provided in [7]. For this proposal, it was assumed a transparent satellite payload as in most of current satellite systems which means that no digital processing units are available in the satellite.

In order to pre-compensate the satellite payload in Fig. 1, an adaptation of the Band-limited (BL) DPD technique proposed in [3] is suitable to be implemented in the transmitter and then try to remotely mitigate the nonlinear effects in the satellite payload. This technique allows transmission of a predistorted signal while satisfying the transmitter uplink spectrum mask. However, the accurate identification and the effectiveness of the BL-DPD block is damaged by the strong frequency-dependent effects of both the IMUX and OMUX filters as it is shown in following subsections. Notice that the TWTA is located in between the two filters, causing the static and dynamic characteristics of the power amplifier to be masked by the IMUX and OMUX linear characteristics.

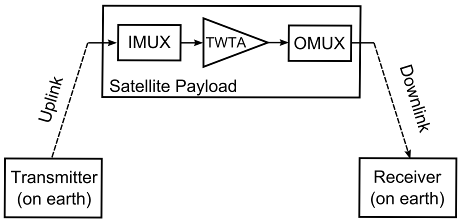

Fig. 1. Functional model of a transparent satellite communication system

In particular, the OMUX filter presents a non-flat group delay response exhibiting variations up to 0.04 us inside the band of interest as illustrated in Fig. 2. This is a very important issue when in a multicarrier scenario the outer bands are close to the edges of both filters severely damaging the performance of those carriers. Fig. 2 has been obtained accordingly to [7], Annex H.7.

For real satellite applications, even if a DPD model is accurately identified employing on-earth measurements taken prior to the satellite launch, there are remaining two important issues. Firstly, the DPD is a nonlinear block not designed to deal with strong linear effects and secondly, the predistorted signal passes through the IMUX filter first, which degrades the nonlinear memory effects compensation the DPD was identified for.

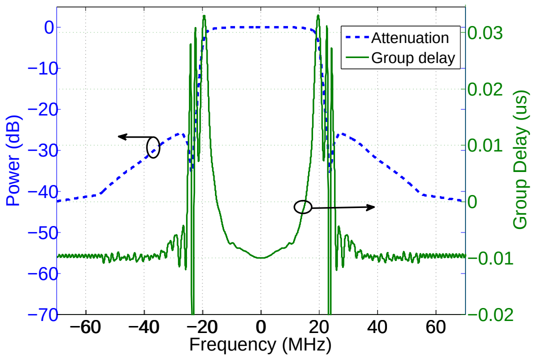

Fig. 2. Magnitude and group delay responses of the OMUX filter

The proposed linear pre-compesation technique: This technique is aimed to deal with the linear effects introduced by the IMUX and OMUX filters mainly due to their group delay characteristics along the satellite transponder bandwidth. To mitigate these undesirable effects, a pre-compensator filter with complex coefficients can be employed such as:

$$\tilde{y}(n) = \sum_{q=0}^{Q-1} \tilde{h}\,(q)\,\tilde{x}(n-q), \tag{1}$$

where the linear complex kernel is represented by $\tilde{h}\,(q)$, with q the index used to represent the memory depth that consider Q delay taps while $\tilde{y}(n)$ and $\tilde{x}(n)$ represent the complex baseband output and input signals, respectively.

As the pre-compensation block constitutes a particular case of the Volterra series formulation employed for most DPD techniques, there is a strong synergy between these individual sub-modules. This facilitates the efficient integration of both in the communication system and their implementation in an FPGA. The full pre-compensation solution can be implemented in the transmitter as shown in Fig. 3.

The coefficients involved in this pre-compensation model are identified with the subsystem consisting if the IMUX filter followed by the OMUX filter, removing the TWTA from the satellite payload. This is possible

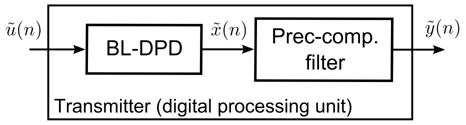

Fig. 3. Architecture of the full pre-compensation system in the transmitter

because the characteristics of those filters are reported in [7], Annex H.7. In (1), the output from the OMUX filter is employed as the signal $\tilde{x}(n)$ while the input to the IMUX is $\tilde{y}(n)$. Then, following the same procedure as in a DPD model identification, the coefficients are estimated in a least-square-error sense [1]. The original functionality of both filters is preserved when employing the proposed technique. It was found that $Q = 45$ is the optimum value necessary to pre-compensate the system under study. It is important to mention that only once this block has been identified and implemented in the system, a proper identification of the preceding block, the DPD, aimed to deal with the remaining nonlinear distortion, is achievable. This is verified in the following subsection.

Validation of the proposed technique: The validation of the full communication system has been accomplished under the DVB-S2 standard specifications using TOPCOM++ components libraries. This platform is widely employed to simulate the expected performance of the real satellite communication system by the European Space Agency (ESA). The communication blocks in Fig. 1 have been assembled in this simulation platform and white Gaussian noise has been added to the downlink signal (satellite payload output), all according to [7, 8]. A two-carrier signal is employed with symbol rate per carrier of 18 Mbaud, RRC filters roll-off of 0.2, carrier spacing of 18 MHz and a digital modulation with a 16-APSK constellation and coding rate 3/4. The IMUX and OMUX filters define the satellite transponder bandwidth in 36 MHz and a linearized TWTA is employed. The full communication system operates at 288 Msps, allowing a generous oversampling factor of 16.

The total link degradation (TD) is a suitable figure of merit to analyse the performance of the communication system. The formulation employed in DVB-S2 is defined in [8], Annex F. Fig. 4 shows the TD performance against the input back-off (IBO) for different cases under study when a bit error rate of 1×10^{-4} is fixed. The carrier 1 has been shifted left in the transmitter side and later it has been shifted right at the receiver. The inverse operations were applied to carrier 2. In Fig. 4 it can be seen that, without any pre-compensation applied, both carriers exhibit poor performance and the communication system cannot operate under such conditions. This highly distorted performance is due to the fact that a significant portion of the information carrying signal is located at or near to the IMUX and OMUX filters edges, where group delay characteristics are very aggressive as shown in Fig. 2. That introduces a large amount of inter-symbol interference due to linear memory effects. Furthermore, because of the TWTA located between those filter, a nonlinear channel is contributing to the in-band distortion in each carrier and also to the inter-carrier interference.

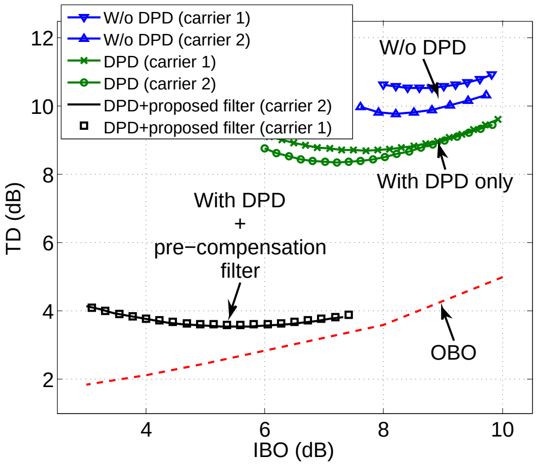

Fig. 4 *Comparison of the TD performances obtained from TOPCOM++ for the different cases under study*

Output back-off (OBO) versus IBO in red-dashed line

The second pair of curves in Fig. 4 has been obtained when trying to address the problem applying only a predistortion technique. Despite the spent efforts on finding a DPD for such kind of scenario, a proper identification of the DPD coefficients is not possible as it is shown by the green lines marked with circles and crosses in Fig. 4. Only when the proposed pre-compensation filter was set up, an accurate identification of the DPD coefficients was achievable. After obtaining the two set of coefficients (DPD and linear pre-compensation filter blocks), the communication signal goes across the DPD block first and the pre-compensation filter later as it is illustrated in Fig. 3. The proposed architecture allows to generate the pre-distorted signal needed to compensate the undesirable effects introduced by the satellite payload. This solution allows a good system performance as Fig. 4 reveals and at the same time, the DPD block has been correctly implemented with less number of coefficients than those employed when the DPD was the only block implemented in the system to pre-compensate the impairments in the satellite payload.

The algorithm described above has been implemented in a Xilinx's Virtex 7 family FPGA. The performance of the implemented algorithm was compared with a 64-bit full precision reference signal extracted from TOPCOM++. The normalized mean square error (NMSE), a widely-used time-domain waveform metric, has been employed for this purpose as in [1]. Six different sets of data (100K complex samples each) were measured from the FPGA board showing a sustained value of -64.2 dB, which is equivalent to an error vector magnitude (EVM) of 0.02 %. The input data was processed by the FPGA as it would be demanded by a real-time application, generating an output sample on each rising-edge of a 288 MHz clock.

Conclusion: A full digital pre-compensation technique has been proposed to mitigate the linear impairments in a transparent satellite payload. Besides allowing an accurate identification of the DPD block to deal with the nonlinearities in the satellite, this technique relaxes the DPD characteristics due to the cancellation of most of the memory effects in the channel. The proposed pre-compensator solution exhibits considerable TD gains in highly distorted systems. Furthermore, the technique has been demonstrated suitable for real-time applications by means of its FPGA implementation.

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