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NONLINEAR INTERFERENCE OF MULTICARRIER MODULATION OVER SATELLITE LINK USING VOLTERRA FILTER

K SINDHUJA

Assistant Professor, Dept of ECE, Apollo Engineering College, Chennai, Tamilnadu, India.

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Abstract: The analytical characterization of the nonlinear interference that results when passing more than one high-order modulation carrier through the same nonlinear transponder high-power amplifier. A Volterra filter is proposed which is novel in its implementation of this analytical characterization and modeling of inter symbol interference and adjacent channel interference. The focus is on adaptive algorithms with pilot-based training so that the solutions are completely blind to unknown transponder HPA characteristics, and can rapidly respond to varying operating back-off level. Furthermore, two families of adaptive solutions are provided to compensate for nonlinear ISI and ACI. The first set performs adaptive channel inversion and then applies equalization. The second set of solutions performs adaptive channel identification and then applies cancellation. The effectiveness of the proposed analysis and techniques is demonstrated via extensive simulations for high-order QAM and APSK modulations. It is also included the coded performance with selected LDPC codes designed for the DVB-S2 standard. Finally, computational complexity is assessed and performance impact is quantified when complexity is reduced by decreasing the number of Volterra coefficients.

Keywords: Adjacent channel Interference, Inter symbol interference, Non linear transponders, Volterra filters, Adaptive equalizers, Adaptive cancellers, Satellite communication, Multicarrier.

Corresponding Author: MS. K. SINDHUJA

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INTRODUCTION

ACI can seriously impair performance if left unmitigated in bandwidth efficient communication systems. Beidas, El-Gamal, and Kay have developed algorithms for iterative interference cancellation to allow proper operation of satellite systems with channel spacing that is smaller than the symbol rate. Two classes are considered depending on whether or not FEC decoding is implemented jointly with interference cancellation in a Turbo-like structure. Joint channel synchronization for this interference-limited satellite application is provided using pilot symbols and is derived using maximum-likelihood methods. In this project, extend the work and provide adaptive compensation for ACI in the presence of a satellite transponder that possesses nonlinear characteristics. With the proposed techniques, it is possible to attain both high bandwidth efficiency and high power efficiency. High bandwidth efficiency is achieved by spacing channels more tightly and by employing modulation with large alphabet size. High power efficiency is achieved by driving the transponder HPA closer to its saturation point.

2. RELATED WORK

Matlab is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses includes.

Math and computation

Algorithm development

Modeling, simulation, and prototyping

Data analysis, exploration, and visualization

Scientific and engineering graphics

Application development, including Graphical User Interface building

SCOPE OF THE PROJECT

In this work, the focus on systems that pass more than one high-order modulation carrier through the same nonlinear satellite transponder HPA and the introduce analytical characterization of the resulting nonlinear interference. It is shown that ISI and several terms of ACI are present, all of which follow a Volterra series expansion. A Volterra filter is then proposed, the novel aspect of which is its implementation of this analytical characterization and incorporation of nonlinear ISI and ACI. The coefficients of the Volterra filter are automatically adjusted through pilot-based training using the superior recursive least-squares (RLS) adaptation method. Furthermore, two families of adaptive compensation techniques are provided to mitigate the nonlinear ISI and ACI. Members within each family of solutions provide a trade-off between performance and complexity. The effectiveness of the proposed analysis and techniques is demonstrated via extensive simulations for high-order QAM and APSK modulation schemes. Coded performance with some selected LDPC codes designed for the DVB-S2 standard is also provided. Finally, considerations of computational complexity are made, including quantifying the performance impact of reducing complexity by decreasing the number of Volterra coefficients.

4. EXISTING SYSTEM

The Compensation for nonlinear ISI in the single-carrier case is performed. Falconer and Benedetto and Biglieri have applied Volterra series to the design of nonlinear equalizers. The LMS algorithm is applied to provide adaptive computation of the nonlinear equalizer coefficients. Alternatively, nonlinear ISI can be mitigated at the transmitter by using predistortion with memory as described. The performance of an end-to-end Turbo-coded APSK is introduced with synchronization sub-systems in the presence of satellite nonlinearity.

DISADVANTAGES OF EXISTING SYSTEM

ISI is present

In LMS low convergence

Single carrier is used

5. PROPOSED SYSTEM

In this work, the focus on systems that pass more than one high-order modulation carrier through the same nonlinear satellite transponder HPA and it introduce analytical characterization of the resulting nonlinear interference. It is shown that ISI and several terms of ACI are present, all of which follow a Volterra series expansion. A Volterra filter is then proposed, the novel aspect of which is its implementation of this analytical characterization and incorporation of nonlinear ISI and ACI. The coefficients of the Volterra filter are automatically adjusted through pilot-based training using the superior RLS adaptation method. By being adaptive, the Volterra filter can be completely blind to unknown transponder HPA characteristics, and can rapidly respond to varying operating back-off level. Furthermore, two families of adaptive compensation techniques are provided to mitigate the nonlinear ISI and ACI. The first set performs adaptive channel inversion and then applies an equalizer on the main path of the received signal. The second set of solutions performs adaptive channel identification and then applies cancellation of the estimated interference. Members within each family of solutions provide a trade-off between performance and complexity. The effectiveness of the proposed analysis and techniques is demonstrated via extensive simulations for high-order QAM and APSK modulation schemes. Coded performance with some selected LDPC codes designed for the DVB-S2 standard is also provided. Finally, considerations of computational complexity are made, including quantifying the performance impact of reducing complexity by decreasing the number of Volterra coefficients. The analysis and the associated nonlinear compensation techniques for ISI and ACI investigated in this paper for the two-carrier case can be extended to the scenario of sharing the nonlinear transponder HPA by more than two carriers, modulated by QAM or APSK.

5.1 ADVANTAGES OF PROPOSED SYSTEM

- High bandwidth efficiency
- High power efficiency
- Multi carrier transmission is possible
- ISI and ACI is cancelled

6. RECURSIVE LEAST SQUARES

The Recursive least squares (RLS**)** adaptive filter is an algorithm which recursively finds the filter coefficients that minimize a weighted linear least squares cost function relating to the input signals. RLS exhibits extremely fast convergence. However, this benefit comes at the cost of high computational complexity, and potentially poor tracking performance when the filter to be estimated (the "true system") changes

7. FORWARD ERROR CORRECTION

Forward error-correction coding (also called channel coding) is a type of digital signal processing that improves data reliability by introducing a known structure into a data sequence prior to transmission or storage. This structure enables a receiving system to detect and possibly correct errors caused by corruption from the channel and the receiver.

7.1 Types of FEC

The two main categories of FEC codes are block codes and convolutional codes. Block codes work on fixed-size blocks (packets) of bits or symbols of predetermined size. Practical block codes can generally be decoded in polynomial time to their block length. There are many types of block codes, but among the classical ones the most notable is Reed-Solomon coding because of its widespread use on the Compact disc, the DVD, and in hard disk drives. Golay, BCH, Multidimensional parity, and hamming codes are other examples of classical block codes.

8. INTERLEAVER AND DEINTERLEAVER

Interleaving is a technique commonly used in communication systems to overcome correlated channel noise such as burst error or fading. The interleaver rearranges input data such that consecutive data are spaced apart. At the receiver end, the interleaved data is arranged back into the original sequence by the de-interleaver. As a result of interleaving, correlated noise introduced in the transmission channel appears to be statistically independent at the receiver and thus allows better error correction.

8.1 HIGHER ORDER MODULATION

Phase-shift keying (PSK) is a digital modulation scheme that conveys data by changing, or modulating, the phase of a reference signal (the carrier wave). Any number of phases may be used to construct a PSK constellation but 8-PSK is usually the highest order PSK constellation deployed. With more than 8 phases, the error-rate becomes too high and there are better, though more complex, modulations available such as quadrature amplitude modulation QAM.

8.2. PULSE SHAPING FILTERS

In digital telecommunication, pulse shaping is the process of changing the waveform of transmitted pulses. Its purpose is to make the transmitted signal better suited to the communication channel by limiting the effective bandwidth of the transmission. Examples of pulse-shaping filters that are commonly found in communication systems are:

- The trivial boxcar filter
- Sinc shaped filter
- Raised-cosine filter
- Gaussian filter

8.2 HIGH POWER AMPLIFIERS

In wireless communications, for higher power efficiency the HPAs are driven close to saturation. The HPAs are found to introduce nonlinear amplitude and phase distortion when operated near saturation. This causes degraded bit-error rate (BER) performance and also introduces adjacent channel interference (ACI) to systems operating in the neighboring frequency bands.

8.4 TRANSPONDER

A transponder is an automatic electronic monitoring or control device that receives, cross-examines, amplifies and retransmits the arriving signal. It is primarily implemented in wireless communication. The word 'Transponder' itself is a combination of two words; transmitter and responder (occasionally abbreviated to TPDR, TR, XPNDR, and XPDR)

8.5 CHANNEL MODEL

The channel model is used to approximate the way errors are introduced in a data stream when it is transmitted over a lossy medium. The two models you may use in the Workshop are the Binary Symmetric Channel (BSC) and the Additive White Gaussian Noise channel (AWGN). Both of these channel models are memoryless, meaning that the distortion of one bit is independent of all other bits in the data stream.

8.6 VOLTERRA THEORY

Volterra theory was developed by Vito Volterra, the Italian mathematician towards the end of the nineteenth century. He extended the idea of linear convolution to include nonlinear models as well. The output, y(t), of a linear time-invariant (LTI) system with impulse response h(t) and input u(t) is given by,

$$y(t) = \int_{-\infty}^{\infty} h(s)u(t-s)ds$$

The corresponding equations in discrete time for linear and nonlinear time-invariant systems, respectively, are as follows:

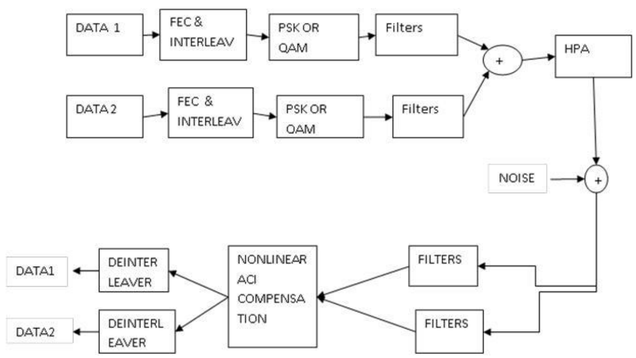
$$y(n) = \sum_{m=-\infty}^{\infty} h(m)u(n-m)$$

Most linear/nonlinear systems have finite memory. Also, in many cases only the lower order kernels (first two or three) are dominant and the higher order kernels have negligible effect on system response; such systems are called weakly nonlinear. However, even if the system is not weakly nonlinear, for the sake of computational feasibility the volterra series is truncated to a finite degree. For finite memory and finite degree, the truncated Volterra series can be represented as below.

$$y(n)=h_0+\sum_{p=1}^{p}\left\{\sum_{m_1=1}^{M}\dots\sum_{m_p=1}^{M}h_p(m_1,\dots,m_p)u(n-m_1)u(n-m_2)\dots u(n-m_p)\right\}$$

The Volterra filters are linear-in-parameters and have been applied to a range of applications in nonlinear system modeling and analysis like channel identification, echo cancellation, etc.

9. SYSTEM MODEL



The system model considered in this paper is displayed in the figure and includes the situation of ACI in which there are two data sources that are identical and independent. In the system with no FEC coding, the data symbols are directly Gray encoded onto M-ary two-dimensional signal constellation such as QAM or APSK at the rate of Ts. In an FEC-coded system, the information bits are passed through a linear binary encoder. The code bits at the output of the FEC encoder are interleaved, Gray encoded and mapped onto the signal constellation.

These symbols are then processed by pulse-shaping filters with impulse responses Pm, T(t);m = 1, 2, to generate

$$s_m(t)=\sum_{k=-\infty}^{\infty}a_{m,k}\,.\,p_{m,T}(t-kT_s-\epsilon_m T_s),$$

Where $\{a_{m,k}\,;\, m=1,2\}_{k=-\infty}^{\infty}$ are sets of complex valued data symbols and p m represents the normalized difference in signal arrival times. More generally, the filter $p_{m,}(t)$ models

The cascade of pulse-shaping filter and the on-board input multiplexing filter. These waveforms are then frequency-translated to their respective slot or center frequency. The composite signal can then be described in complex form as

$$s_c(t) = s_1(t)\frac{e^{j(2\pi f_1 t+\theta_1)}}{2} + s_2(t)\frac{e^{j(2\pi f_2 t+\theta_2)}}{2}$$

Where, are the center frequency and carrier phase of the -th channel, respectively.

The HPA in the satellite transponder is modeled as a nonlinear memory less device. Its input-output relationship can be expressed as a power series

$$s_{NL}(t) = \sum_{t=0}^{\infty}\gamma^{(2l+1)}.[s_c(t)]^{l+1}.[s_c^*(t)]^{l}$$

Where $\{\gamma^{(2l+1)}\}$ is a set of complex-valued coefficients that

Accounts for AM/AM and AM/PM distortions. The absence of even-order product terms due to the band pass nature of the nonlinearity which produces contribution that is outside the frequency band of interest. The signal is then contaminated by the downlink noise so the input to the receiver is ( )

$$r(t) = s_{NL}(t) + n(t)$$

Where the accompanying noise ( ) is the standard additive white Gaussian noise (AWGN) with single-sided power spectral density (PSD) of 0 (Watt/Hz). The lower portion represents the schematic of the receiver that includes a bank of receive filters to frequency translate each carrier to baseband and to apply a filtering operation with impulse response ,( ) so that the noise is rejected in the non-signal band. The input-output relationship of the -th receive filter bank is expressed as

10. ANALYTICAL CHARACTERIZATION OF NONLINEAR INTERFERENCE

It introduce analytical characterization of the nonlinear interference that results when operating two high-order modulation carriers through the same satellite transponder HPA and provide explicit expressions for the first-order and third-order ISI and ACI at the receive filter bank.

A. First order interference

B. Third order interference

The first-order ISI is

$$ISI_1^{(1)} = \gamma^{(1)} . \sum_{\substack{k=-\infty \\ k \neq n}}^{\infty} a_{1,n-k} . h_{11}^{(1)} \left(kT_s ; 0 \right)$$

The third-order ISI at the first branch of the receive filter bank as

$$ISI_1^{(3)} = \frac{\gamma^{(3)}}{2} \sum_{k_1=-\infty}^{\infty} \sum_{k_2=-\infty}^{\infty} \sum_{k_3=-\infty}^{\infty} a_{1,n-k_1} . a_{1,n-k_2} . a_{1,n-k_3}^{*} . h_{1111}^{(3)} \left(k_1 T_s , k_2 T_s , k_3 T_s ; 0 \right).$$

11. ADAPTIVE VOLTERRA FILTER FOR TWO CARRIERS

The Volterra filter that follows the analytical characterization developed. For practical considerations, we study the Volterra series expansion which is truncated in the order of the nonlinearity to 3 and is truncated in time to double-sided memory length of symbols (will be chosen later to be 3). The input-output relationship for the Volterra filter that incorporates ACI is expressed as

$$y_1^{(3)},VF(n) = \underline{w}_1^H . \underline{\tilde{u}}_1^{(3)}, NLC (n).$$

The Nonlinear combiner of the 3rd-order that only incorporates ISI(1) 1 , ACI(1) 1 (+Δ), ISI(3) 1 , and ACI(3) 1 (0), described as

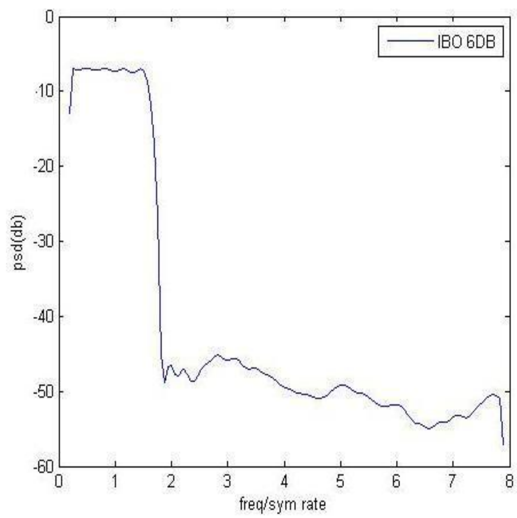
$$\underline{u}_{1,NLC}^{(3)}(n) = \begin{bmatrix} \underline{u}^{(1)}(n) \\ \underline{u}_{(2)}(n).e^{j(2\pi\Delta f(n+\epsilon_1)T_s+\Delta\theta)} \\ \underline{u}_{111}^{(3)}(n) \\ \underline{u}_{122}^{(3)}(n) \end{bmatrix}$$

12. COMPENSATION FOR NONLINEAR INTERFERENCE

The first set implements nonlinear compensation through RLS equalization while the second set implements nonlinear compensation through RLS interference cancellation. Members in each family of solutions are different depending on the nonlinear terms included in the nonlinear combiner.

- RLS Volterra Equalizers with ACI Compensation
- RLS Volterra Cancellers with ACI Compensation

13. SIMULATION RESULTS



The carriers are modulated by 16QAM with frequency spacing off. The transmit and receive filters are matched pair of root-cosined filters with a roll off factor of 0.25. The synchronization of the receiver is ideal. The nonlinear satellite transponder HPA model shared by modulation carriers follows the sale h model. Specifically, the nonlinearity is characterized, in terms of the amplitude or by the following AM/AM and AM/PM conversions. The simulated power spectral density of the transmitted Signal Snl (t), at the output of nonlinear HPA when operated at the input back-off level 6db is shown in the above graph performance is quantified in terms of total degradation concept it is associated with a target bit error rate as a function of output level.

Two16QAM-modulated carriers, with = 1.25^{-1},

The results in terms of total degradation for uncoded passing through the same nonlinear HPA are displayed in Fig. 5(a) for different compensation techniques. The target uncoded. BER is10^{-3}, for which the required ideal per-bit SNR is = 10.5dB. With no compensation (only a fixed amplitude and phase correction), TD_{min} = 7.43dB at OBO_{opt} = 6.1dB. The LMS Volterra equalizer reduces the minimum total degradation TD_{min}=6.24dB at OBO_{opt} = 4.62dB.Increasing the length of the training sequence in the LMS adaptation to 20, 000 symbols improves the minimum total degradation by 0.1dB and the optimal back-off by 0.3dB. Replacing the LMS adaptation method with the RLS algorithm further reduces the minimum degradation to TD_{min}= 5.96dB at OBO_{opt}=4.29dB.The RLS canceller without ACI compensation gives TD_{min}= 5.83dB at the same OBO_{opt}. A large reduction in both total degradation and back-off level is obtained using the presented RLS Volterra equalizer and canceller which incorporate ACI compensation.

As can be seen in the figure, the RLS Volterra equalizer with ACI compensation allows one to lower the minimum total degradation to TD_{min} = 5.08dB at OBO_{opt}=3.38dB. An additional reduction of 0.4dB in the minimum total degradation is possible with the RLS Volterra canceller that incorporates ACI compensation.Fig.4 contains the corresponding results for 16APSK and exhibits similar behavior. The 16APSK constellation used has 4 points on the inner ring and 12 points in the outer ring, with a ring-ratio of 2.732 selected to maximize the minimum Euclidean distance. The target uncoded BER is 10^{-3}, for which the required ideal per-bit SNR is */n0,=1* An extensive Monte-Carlo simulation study is carried out to demonstrate the effectiveness of the two families of adaptive compensation techniques described in this paper for the uncoded and FEC-coded situations.

The simulation setup implements the transmission and receive filters, ( ) and , ( ), are a matched pair of root-raised cosine (RRC) filters with a roll off factor of 0*.25.* The two modulated carriers follows the Saleh model with parameters as used in reference. Specifical $_{NL}$ ( ), at the output of the nonlinear HPA when operated at two different input back-off levels is illustrated by, the nonlinearity is characterization concept, used in 9th and 12th reference, associated with a target bit error rate (BER) as a function of output back-off (OBO the, the output of the receive filter bank contains nonlinear ISI and several terms the output graphs.

During training, the filter weights are adaptively adjusted so as to provide the “best inverse" of the nonlinear channel. To achieve this, we compose the input vectors from samples of the receive filter output and let the desired sequence be equal to the actual compensation techniques for the nonlinear interference that is present. An adaptive Volterra filter is introduced, the novel aspect of which is its implementation of this analytical characterization and modeling of ISI and ACI. Two families of adaptive nonlinear compensation techniques of ISI and ACI are then presented.

The performance of the compensation techniques that incor-porate ACI is investigated when DVB-S2 LDPC codes are employed. Results are provided for the DVB-S2 short frame (16200 coded bits) and code rate of 8/9. The target coded BER is 10^{-5}, for which the required ideal per-bit SNR is 7.21dB for 16QAM and 7.45dB for 16APSK.

Fig. 6(a) illustrates the total degradation versus OBO when the nonlinear HPA is shared by two carriers modulated by

LDPC-coded 16QAM. The presence of the powerful channel code allows for signaling at lower SNRs where nonlin- ear distortion gets masked by the noise [13], [7]. Despite the capacity-approaching channel code, the presented RLS Volterra canceller with ACI compensation can still provide large performance improvement relative to no compensation. When = 1.25 $^{-1}$, the minimum total degradation is reduced by 1.6dB, coupled with better HPA utilization by

Fig5. Total degradation of LDPC-coded performance versus OBO of RLS Volterra canceller, with ACI compensation, for two-carrier (5) 1 6 A P S K t h r o u g h n o n l i n e a r reducing OBO $_{level}$ by 1.6dB. With tighter carrier spacing of The complexity of the discussed methods of compensation is assessed in terms of the number of complex multiplications used. Compensation has comparable complexity whether achieved via equalization or interference cancellation. How- ever, the difference is mainly due to the usage of different nonlinear combiners within each family of compensators. The lowest-performing Volterra filter employs the nonlinear combiner (28), designed for the single-carrier case and models only ISI. The second member is the nonlinear combiner (29) which models ISI and partial ACI. The third member is the nonlinear combiner (30) that models more ACI terms.

The operation of multicarrier modulation carriers passing through the same nonlinear transponder HPA is addressed. An analytical characterization of the resulting nonlinear ISI and ACI is provided and is shown to follow a Volterra series representation. An adaptive Volterra filter is introduced, the novel aspect of which is its implementation of this analytical characterization and modeling of ISI and ACI. Two families of adaptive nonlinear compensation techniques of ISI and ACI are then presented. Members within each family of techniques provide trade-off between performance and complexity. Extensive simulations have shown that significant performance gain can be achieved with the proposed analysis and techniques.

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