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Development of hybrid envelop memory polynomial based predistorter for RoF system

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ABSTRACT

Radio over Fiber (RoF), an empowering innovation for dissemination of wireless broadband service signals through simple optical connections experiences non-linear distortion. We have designed and implemented a novel predistorter model to reduce nonlinear distortion using hybrid envelop memory polynomial (HEMPM) for the RoF system. The link gives satisfactory performance in the range of GHz signal. The designed algorithm is superior to popular approaches like memory polynomial model (MPM) and envelop memory polynomial model (EMPM) in terms of order of the memory and degree of non-linearity. As per author's the best knowledge, this is exclusively first time result obtained for HEMPM technique for RoF link and also, for MPM, EMPM based predistorter for RoF link using MATLAB – OptiSystem co-simulation. The results shows that adjacent channel power (ACP) is suppressed by ~0.45 dB m, ~28.4 dB m and ~7.65 dB m of MPM & EMPM and HEMPM model for $K=5$ & $Q=2$ whereas for $K=7$ & $Q=3$ the value of suppressed power is ~36.3 dB m, ~47.7 dB and ~05.8 dB m, respectively as compared to input signal. NMSEs for ($K=7$) and memory length ($Q=3$) reduced by ~−5.003 dB m for HEMPM model and increased by ~−4.13 dB m for MPM model. The EVM is increased from ~1.56% to ~1.96% for HEMPM model and increased from ~4.38% to ~14.73% for MPM model for $K=7$ & $Q=3$.

1. Introduction

The field of the optical communication is developing step by step and demand of the high information rate and least activity blockage [1]. The number of mobile subscribers, machine to machine communication and immense utilization of web (such as YouTube, Hotstar, Playstore, Skype, Facebook & Twitter and so forth) are expanding the demand of bandwidth & requirement of anywhere anytime network facilities. According to the cisco global IP traffic in 2014 was 59.9 exabytes per month and will nearly triple by 2019, to reach 168.4 exabytes per month. Consumer IP traffic will reach 138 exabytes per month and business IP traffic will surpass 29.6 exabytes per month [3].

In Fig. 1(a), RoF link response in blue color represents response without the predistorter (b) Inverse model of RoF response (c) Black dotted response shows the RoF link with predistorter. The Radio over Fiber (RoF) technology is one of the promising strategies to overcome problem of present networking and will resolve, the critical issues of upcoming state-of-the-art technologies [4,5]. In RoF technique the RF signals of ≈ GHz range are modulated with photonics carrier of order ≈ THz and optical fiber is used as guided media to propagate the optical modulated signal. Various E/O & O/E conversion produce the nonlinear distortion (NLD) [6]. Some of investigators suggest the higher order adaptive filter predistortion scheme [7], amplitude & phase [8], direct learning algorithms [9], digital signal processing [10], dispersion compensation [11], feedback [12], feedforward [13] and predistortion technique [14] to reduced NLD for RoF link. These techniques are measured for different parameter like chromatic dispersion reduction [15], harmonic distortion and inter-modulation [16], nonlinearity of machzender modulator (MZM) [17], stimulated brillouin scattering [18], and effect of modal noise [19]. In view of the fact that in RoF there is a conversion of domain from E/O and vice versa, the impacts of signal impairment in both the changes are to be considered for RoF.

In electrical domain the linearization techniques are divided into two types: analog predistortion & digital predistortion where as in optical domain it is the mixed polarization, dual wavelength, optical channelization etc [20].

2. Predistortion techniques

Predistorter is used to generate inverse nonlinearity characteristic of the received signal to compensate the nonlinearity of RoF system digitally [21]. In Fig. 1 it is clearly indicated that nonlinear

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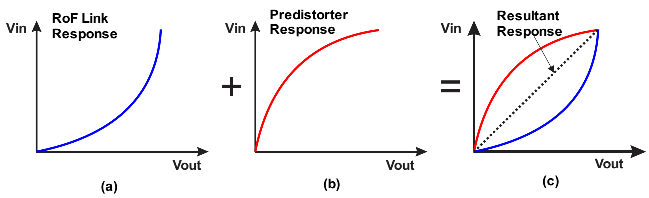

Fig. 1. Predistortion technique to compensate the nonlinear response of RoF link

response of RoF gets mitigated by modifying the input signal using predistorter inverse modeling and linear response of the received signal is achieved. Numerous behavioral models are use to describe the predistorter model for linearization of RoF system [22,23]. The Volterra model [24], Wiener model [25], Parallel-Wiener model [26], Wiener–Hammerstein model [27], memory polynomial Model (MPM) [28], envelop memory polynomial model (EMPM) [29] are proposed for predistorter model. The memory effect may very important role to design a predistorter especially in RoF system. The additional exactitude can be acquired when it is implemented to evaluate nonlinear practices than memory less RoF transmission [30]. These models have been examined in distinctive angles and are suited for diverse sorts of uses requiring variable memory and coefficients. A Volterra series approach is one of the methods which can precisely model the nonlinear system with limitations of increased complexity due to more coefficient requirement [31]. The graphical representation of RoF link response generate the predistorter characteristic and it will be act as trademark for behavioral modeling of predistorter of different polynomial structure like MPM, EMPM. Nonlinear system has two categories: without memory effect and with memory effect. All of the nonlinear effects of present, but the additional property of frequency dependence in the AM/AM and AM/PM coefficients may be observed. Mathematical model for without memory & with memory effect are described in Eqs. (1) and (2), respectively. The system consists of narrow band amplitude modulated signal, $\tilde{\mathbf{x}}(\mathbf{t})$ at carrier frequency ω represented by

$$\tilde{x}(t) = A(t)\cos\left[\omega t + \theta(t)\right] \tag{1}$$

The output signal of the system includes an infinite number of harmonic and intermodulation **components** and the bandpass component, $\tilde{\mathbf{y}}(\mathbf{t})$ around ω can be represented by:

$$\tilde{\mathbf{y}}(\mathbf{t}) = \mathbf{G}[\mathbf{A}(\mathbf{t}), \boldsymbol{\omega}]\,\mathbf{cos}\left\{\left[\boldsymbol{\omega}\mathbf{t} + \boldsymbol{\theta}(\mathbf{t}) + \boldsymbol{\phi}\mathbf{G}\left[\mathbf{A}(\mathbf{t}), \boldsymbol{\omega}\right]\right\}\right. \tag{2}$$

where $G[A(t)]$ represents the AM/AM conversion characteristic and ϕ $G[A(t)]$ is the AM/PM conversion characteristic and both can be seen as an envelope-dependent complex gain function. Appropriate modeling requires that consideration be paid to the frequency characteristics of the nonlinearities. The Volterra model can be presented as follows:

$$y(n) = \sum_{k=1}^{k}\sum_{i_k=1}^{Q} h_k(i_1, \ldots, i_k) \prod_{j=1}^{k} x\left(n - i_j\right) \tag{3}$$

where $x(n)$ and $y(n)$ represent the input and output of the model, respectively, $h_k(i_1, \ldots, i_p)$ is the kth-order Volterra kernel, k is the nonlinearity order, and Q is the memory length. At least for higher order nonlinearities, the kernels are computationally complex and, for the predistortion, pth-order inverse of the Volterra model is difficult to construct. The inverse may not even exist or it exists only in a limited amplitude range. Due to the high complexity, the Volterra series are inappropriate for the practical modeling of the nonlinear system [32]. To reduce the complexity and improve the performance, several modifications of the Volterra model have been proposed in various survey & experiment works.

2.1. Memory polynomial model

This model is another special case of the Volterra model in discrete time and has been extensively used in the literature in a wide variety of applications; especially in the linearization of RoF with memory effect [33]. Special cases of the Volterra model are exhibited by defining their kernel relationships. At last, empirical models that are based on fitting measured characteristics to preset models are introduced. These models are normally used to produce nonlinear characteristics in simulations of nonlinear RoF systems.

MPM is a reduction of the Volterra model where only diagonal terms are kept. The output of the MP model can be described by [34]

$$y(n) = \sum_{k=1}^{k} b_k \sum_{q=0}^{Q} C_{kq}\, x(q-l)\left|x(n-q)\right|^{k-1} \tag{4}$$

where C_{kq} is the coefficient of the MP model. K is the order of nonlinearity, odd only in the present case; and Q is the memory length, which defines the amount of the memory that can be modeled. Since the model in Eq. (4) is linear with respect to its coefficients, the predistorter coefficients b_{kq} can be obtained directly by least squares.

By characterizing a new sequence

$$\mathbf{u_{kq}}(\mathbf{n}) = \frac{\mathbf{y}(\mathbf{n}-\mathbf{q})}{\mathbf{G}}\left|\frac{\mathbf{y}(\mathbf{n}-\mathbf{q})}{\mathbf{G}}\right|^{\mathbf{k}-1}$$

At convergence, we have

$$\mathbf{z} = \mathbf{Ua}$$

where

$$\mathbf{z} = [\mathbf{z}(\mathbf{0}), \ldots, \mathbf{z}(\mathbf{N}-1)]^{\mathbf{T}}$$

$$\mathbf{U} = [\mathbf{u_{10}}, \ldots, \mathbf{u_{K0}}, \ldots, \mathbf{u_{1Q}}, \ldots, \mathbf{u_{KQ}}]$$

$$\mathbf{u_{KQ}} = \left[\mathbf{u_{kq}}(\mathbf{0}), \ldots, \mathbf{u_{kq}}(\mathbf{N}-1)\right]^{\mathbf{T}}$$

$$\mathbf{a} = \left[\mathbf{a_{10}}, \ldots, \mathbf{a_{K0}}, \ldots, \mathbf{a_{1Q}}, \ldots, \mathbf{a_{KQ}}\right]^{\mathbf{T}}$$

The least–square calulation is

$$\mathbf{a} = \left(\mathbf{U^H U}\right)^{-1}\mathbf{U^H z}$$

Whte (.)H represnts a complex conjugate transpose

The MP modeling approach with polynomial functions Fm; the polynomial functions Fm being the same as in the Volterra modeling.

$$\mathbf{F_m}(\mathbf{n}) = \sum_{\mathbf{P}=1}^{\mathbf{P}} \mathbf{C_{pm}}\mathbf{x}(\mathbf{n})\left|\mathbf{x}(\mathbf{n})\right|^{\mathbf{k}-1} \tag{5}$$

It is difficult to obtain an exact inverse of the MP model. Fortunately, another MP can be used for the inverse model.

2.2. Envelop memory polynomial model

For high order of nonlinearity and memory length require a high memory storage and long simulation time. Since the carrier signal does not carry any information, it is usually useful to simulate the “complex envelope” of the modulated signal since this contains all the information in the modulated signal [35]. The complex envelope of modulated signal is the baseband equivalent signal of a modulated signal that contains all the information and at the same time has a maximum frequency that is much lower than the carrier frequency.