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Non-Linear Distortion Noise Removal by Introducing a Static Pre-distortion at the Transmitter

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Abstract: ***Nowadays in the field of electronics there is a considerable shift towards more bandwidth demanding applications. Due to this ongoing shift, more bandwidth consuming applications and services has to be introduced for the next generation which offers higher data rates with reduced cost and traffic. On increasing the bandwidth, signal distortion results which is the alteration of waveform of an information bearing signal. Distortion takes the form of both linear and non-linear type. Since non-linear distortion reduces power and spectral efficiency of transmitted signal which leads to Inter-modulation Interference (IMI), it needs to be mitigated for effective communication. Efficient removal of non-linear distortion noise can be attained by the introduction of a pre-distorter at the transmitter side and performing iterations at the receiver side. This paper presents an effective method for the removal of non-linear distortion, both at the transmitter and receiver section with a pre-distorter at the transmitter side and performing iterations at the receiver side .This is then tested for three commonly used digital transmission schemes TDMA(Time Division Multiple Access), OFDMA(Orthogonal Frequency Division Multiple Access) and SC-FDMA (Single Carrier Frequency Division Multiple Access) which are the commonly used waveforms in terrestrial and satellite communication.***

Keywords: Non-linear distortion, IMI, Pre-distortion, TDMA, OFDMA, SC-FDMA

1. Introduction

The emerging access towards more bandwidth demanding applications initiated a considerable shift in the field of communication towards high bandwidth links offering higher throughput and efficiency. Increased bandwidth along with significant hardware implementations leads to signal distortion. Since, appropriate signal processing techniques has to be implemented both at the transmitter side and at the receiver side to maximize the efficiency and information rate. Distortions takes the form of both linear and non-linear nature. Linear distortion occurs due to the mismatch of spectrum of the signal and the filter spectral response. While nonlinear distortion is mainly because of the nonlinear transfer function of high power amplifiers (HPAs) at the satellite user terminals .This adverse effect of non-linear distortion leads to reduction in spectral efficiency and power and leads to IMI. Intermodulation interference introduces non-linearities in a system by amplitude modulation of signals. Intermodulation between frequency components results in the formation of additional signals which causes harmonic distortion.TDMA is the waveform used in DVB-S2X[4] standard for return satellite links. OFDMA and SC-FDMA waveforms are used in terrestrial mobile networks due to their high spectral efficiency and less traffic [3]. Since, these are the waveforms which are the hearts of communication system, non-linear distortion effects constituting IMI is a problem of concern. IMI reduction by means of power control such as the output and input back-off power was introduced[2], [3]. This approach treated interference as an additional noise and no measure was taken to extract the information contained in the interfering component. The interfering component was estimated [5] using a model for the received constellation centroids based on Bussgang decomposition .This approach is applicable in systems where the non-linear distortion noise and symbols are uncorrelated. When IMI is correlated with the signal, scaling factors for each constellation points has to be estimated. Hence, this approach is applicable for SC-FDMA where the signals and noise are uncorrelated. In [6], a model is presented which is applicable in optical system consisting of a soft limiter amplifier with ideal clipping. This has been implemented in 16QAM.This provides a general model which is only applicable to non-linear transfer characteristics and any digital modulation scheme in an RF OFDMA system. However, when the IMI is correlated with the signal, scaling factors has to be calculated individually. In the efficient removal of non-linear distortion technique has to be adopted to eliminate distortion both at the transmitter side and at the receive side. In [1] non-linear distortion at the receiver section is eliminated by performing a number of iterations by buffering the received signal after demodulation. Pre-distortion being implemented at the transmitter side provides a much better result as the pre-distortion factor get cancels with the distortion factor which initiates nonlinear distortion. Pre-distortion technique inversely models the amplifier distortion providing an inverse distortion which is introduced into the input of the amplifier thereby cancelling nonlinearity.

The paper is organized as follows. Section 2 describes the block diagram and description. Section 3 describes the effects of nonlinear distortion and method to remove nonlinear distortion both at the transmitter side and the receiver side. Section 4 and 5 describes the experimental results including the comparison plot. Finally section 6 concludes the paper.

2. System Model

2.1 Block Diagram

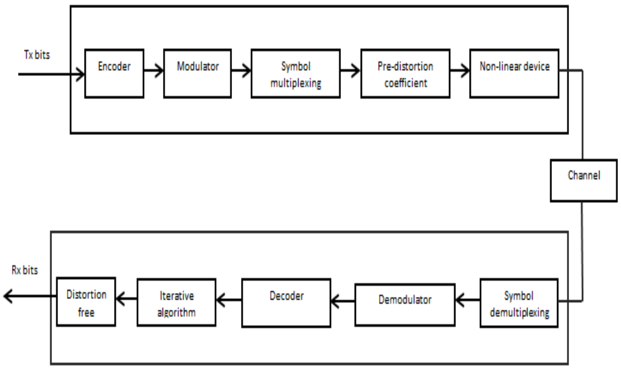

Figure 1: Block Diagram of iterative receiver with predistortion factor at the transmitter

The block diagram consists of a transmitter side and a receiver side. The transmitter side consists of an encoder, modulator, symbol multiplexer, predistortion coefficients being calculated and a device, which can be an amplifier to introduce non-linear distortion .The signal is then transmitted over the communication channel. The received signal which is distorted is demultiplexed, decoded and subjected to iteration to remove the distortion. After successive iterations, distortion free signals are obtained at the receiver side. Encoder is an analog to digital converter which converts the quantized samples into binary data. Modulator is used to vary the parameters of carrier signal in accordance with the modulating signal. Multiplexing is used to combine multiple digital or analog signals into one signal over a shared medium thus improving the capacity of communication channels. An inverse operation known as the demultiplexing is introduced at the receiver to extract the original signal at the transmitter side. The pre-distortion coefficients are then added with the transmitted signal before transmission. Iterative algorithm was introduced to eliminate the nonlinear distortion at the receiver side and the number of iterations depends on the amount of non-linear distortion parameters in it. The added pre-distortion coefficients cancels the distortion coefficients when the signal is passed through the device causing distortion.

3. Iterative Removal of Non-linear Distortion

3.1 Need to remove Non-linear Distortion

The Non-linear distortion in digital communication systems introduces symbol clustering and warping of signal constellation. The IMI which is dependent on the signal waveform consists of useful information of the transmitted signal. In digital transmission schemes such as TDMA, the interfering component which is generally correlated with the transmitted symbols. Hence, each constellation point at the receiver can be individually warped and scaled with respect to original transmit symbol constellation. In OFDMA system, in which the analog carrier is digitally subdivided into a large number of subcarriers a large number of symbol multiplexing will results in in a signal similar to that of a gaussian distributed signal. Signal pre-distortion linearizes the amplifier characteristics at the transmitter side along with iterative algorithm at the receiver eliminates the effect of non-linear distortion.

3.2 Cancellation at the Receiver side

At the receiver the signal received is distorted and is given by:

$$y = h * F(x) + w \tag{1}$$

Here, the interfering component and the signal is decomposed, where the output of the non-linear device is given as:

$$F(x) = kx + d \tag{2}$$

where the output signal $F(x)$ is an attenuated and rotated replica of the information bearing signal 'x', and non-linear distortion noise 'd'. The scaling factor K can be real valued or complex valued based on the non-linear distortion function. This is obtained as the covariance of received and transmitted symbol. Then starting the phenomenon of iteration. First, the received symbols are demodulated and stored in a buffer. Next, the demodulated symbols are used to obtain the estimate of the received signal which is subtracted from the scaled demodulated symbol to obtain the estimate of the interfering component. This is again subtracted from the symbols in the buffer to obtain a new set of received symbols. This new set of received symbols are the output of first iteration and then the second iteration is performed. In the second iteration, this newly obtained symbols are demodulated and then estimated the interfering component which is again subtracted from the originally buffered received symbols. This is the output for the second iteration and after which successive iterations are performed. Finally, the buffer is released and thus a new set of received symbols are obtained which is free of interference. The vector of the detected symbol resulting from the i-th iteration is given by:

$$x^{(i-1)} = \text{Det}\ [\text{Demux}\ [\text{Eq}\ [\text{ADC}\ [y]\ ]\ ]\ ] \tag{3}$$

3.3 Cancellation at the transmitter side

Data pre-distortion is a digital technique which preserves the signal spectrum. Here, the transmit constellation is modified in such a way that the original transmit constellation and received centroids coincide with each other. The nonlinear distortion coefficients are calculated at the receiver side and the inverse of this transfer function is modified. This distortion coefficients are known as the pre-distortion coefficient and added along with the transmitted signal, The distortion causing component along with the pre-distortion factor gets cancels each other and thus distortion free signals are obtained at the receiver side. The introduction of pre-distortion along with the iterations constitutes the elimination of non-linear distortion and noise free signals are obtained at the output side. For this, a threshold level is set above which the value reaches nonlinear distortion. It also performs automatic gain control (AGC) in which scaling of the received constellation symbols to minimize the amount of error component. This method is adopted for OFDMA, SC-

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FDMA and TDMA. The Bit Error Rate (BER) of these three waveforms are analyzed and compared.

4. Experimental Results

MATLAB R2015b is used as the implementation tool. A random signal from the output of the amplifier is given as the input. For making the system more user friendly a GUI window is provided with different buttons and windows.

An audio signal is provided as the input to the transmitter of which the distortion factors are previously estimated. This previously estimated non-linear distortion coefficients are inversely modelled to obtain the pre-distortion coefficient. This predistortion coefficients along with the input signal is given as input to the transmitter. An amplifier is introduced to produce non-linear distortion. Here, the pre-distortion factors along with the distortion factor get cancels each other. The remaining non-linearities can be eliminated by using iterative algorithm. Here the threshold value set for non-linear distortion to take place is 3. Then the BER plot is valuated for TDMA, OFDMA and SC-FDMA. Then the two systems with and without non-linear distortion is compared and thus it is concluded that the system with predistortion at the transmitter showed better result.

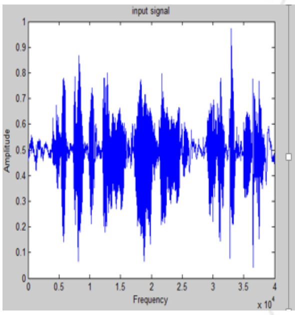

Figure 2: Input Signal

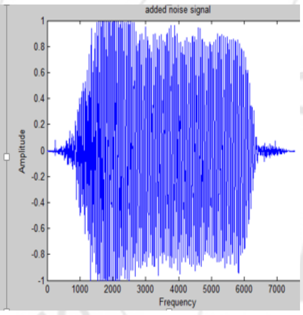

Figure 3: Added noise

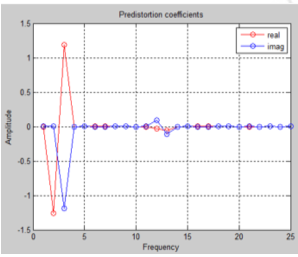

Figure 4: pre-distortion coefficients

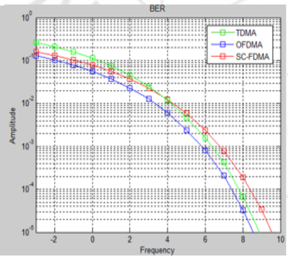

Figure 5: BER

5. Performance Comparison

The performance has been analyzed with and without pre-distortion. The results showed that BER shows a better improvement with pre-distortion. More nonlinear noise component can be eliminated by the introduction of this pre-distorter.

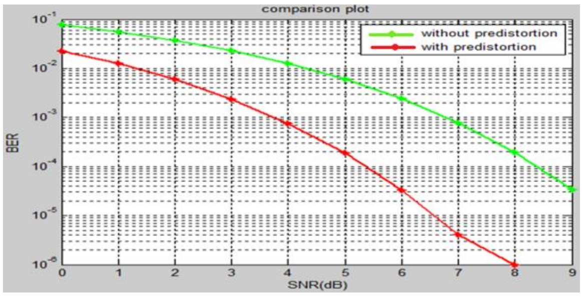

Figure 6: Comparison plot with and without predistortion

6. Conclusion

Non-linear distortion which adversely effects the transmission system has to be removed for reliable communication. Satellite and mobile communication systems which uses TDMA, OFDMA and SC-FDMA along with heavy user traffic, this effect of non-linear distortion is a challenge for the next generation communication system with higher bandwidth. In this paper, a novel receiver has been proposed for the elimination of non-linear distortion by performing iterations at the receiving end and a pre-distorter which inversely amplifies the amplifier characteristics is introduced at the transmitter side. The effect of non-linear distortion elimination factors both at the transmitter and at the receiver showed a better result with less number of iterations.

7. Acknowledgment

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