Generalised backpropagation algorithm for training a data predistorter with memory in radio systems

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Indexing terms: Neural networks, Backpropagation, Digital radio systems

The authors present a neural network based data-predistorter with memory, for the compensation of high-power amplifier (HPA) nonlinearities in digital microwave radio systems. The overall system (predistorter, pulse shaping filter and HPA) can be seen as a unique FIR multilayer neural network, for which a specific complex-valued back-propagation algorithm can be developed to realise the data predistorter. The proposed scheme can also control the spectrum of the signal after the HPA.

Introduction: In many digital radio systems, it is known that the main source of nonlinearity is the saturating high-power amplifier (HPA) used at the transmitter. This nonlinearity affects both the amplitude and phase of the amplified signal, and can be considered as memoryless. However the overall baseband-equivalent system is usually a nonlinear system with memory due to the presence of pulse shaping circuits. The effects of the nonlinear channel with memory on the high-capacity modulation formats, i.e. QAM signals, are many, but three of them have particular relevance: spectral spreading, intersymbol interference (ISI) and constellation warping.

To reduce these effects, it is possible to compensate for the nonlinearity at the receiver (nonlinear equalisation) or at the transmitter (nonlinear predistortion). The latter is used to linearise the HPA characteristic, by predistorting the input signal in such a way that the cascade predistorter-amplifier-receiver resembles as closely as possible an ISI-free channel. Both analogue signal predistortion and data predistortion have been proposed in the past, in particular several different techniques have been proposed for data predistortion [1–3].

The purpose of this Letter is to present a new data predistortion technique which is based on a neural network (NN) approach. The major difference with respect to previous techniques is that now control on the spectral shaping at the output of the HPA can be introduced is possible.

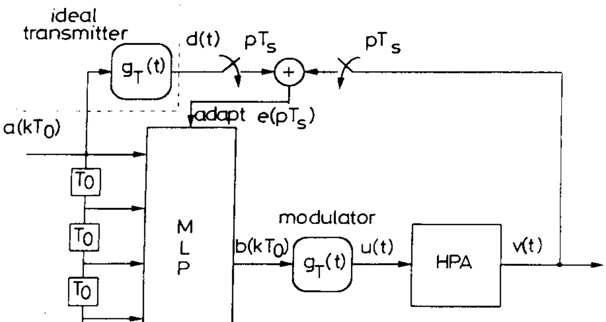

Fig. 1 *Baseband equivalent of radio system with proposed predistortion technique*

Neural network data predistortion: To effectively reduce unwanted nonlinear effects and at the same time minimise cross-channel interference, we have to design a predistorter which minimises the error between the HPA output and the ideal undistorted signal at all instances in time. In practice, if the bandwitdh of the transmitted signal is within $1/(2T_s)$ Hz, where $T_s = T_0/Q$ (T_0 being the symbol period), the adaptation can be made at each instance $\{pT_s\}$. Fig. 1 shows such a scheme where a multilayer perceptron (MLP) is used as a predistorter, $a(kT_0)\}$ is the data stream, $\{b(kT_0)\}$ is the predistorted data stream and $gT(t)$ is the impulse response of the modulator pulse shaping filters (usually a square-root raised-cosine filter with a given roll-off factor a). Such a scheme, with the MLP replaced by a RAM, has also been introduced in [3], where the authors make use of a specific, often undesirable, pulse shape that leads to discrete signal levels at only two or three points per symbol period T_0 at the output of the HPA.

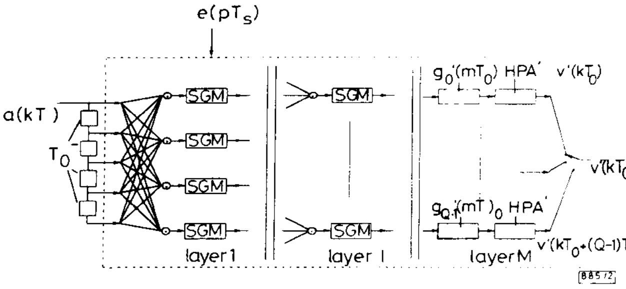

Fig. 2 *Efficient realisation of adaptation scheme*

Based on the error $e(pT_s)$ between the desired signal $d(pT_s)$ and the actual signal $v(pT_s)$, an efficient adaptive scheme to determine the MLP weights is derived (Fig. 2). We note that an estimate of the general model of both modulator and HPA is required (indicated by g' and *HPA'*, respectively) which is used only in the feedback mode to speed-up the convergence process, while the scheme of Fig. 1 is used in the forward mode. If we assume that $g'(pT_s)$ is an FIR filter with $(2L+1)Q$ taps and $\{g'_q(mT_0)\}$ is its polyphase representation, i.e.

$$g'_q(mT_0) = g'(mT_0 + qT_s) \qquad q = 0, 1, ..., Q-1 \qquad m = -L, ..., 0, ..., L$$

then, noting that the MLP works at a much lower rate than the modulator filter, the efficient realisation of Fig. 2 is easily derived. Now, all the filters work at the slowest rate ($1/T_0$). The actual output is derived by cyclically taking the value of each polyphase path output. In Fig. 2, the internal layers of the original MLP have also been included, from layer 1 to layer M–1. The last layer (index M) is the layer comprising the HPA and filtering sections. SMG denotes a complex nonlinear function, analogous to the real-valued sigmoidal function [4].

A specific version of the back-propagation algorithm has been developed to find the coefficients of the neural predistorter by minimising the power of the signal $e(pT_s)$. This algorithm is a complex-valued generalisation of the causal back-propagation method for FIR-MLP [5]. Since each polyphase filter is composed of a delay line, the network of Fig. 2 is actually a complex-valued multilayer perceptron with FIR synapses.

We would like to emphasise that while the training phase is based on such an intricate scheme, the forward phase (normal mode of operation) may be realised either by a simple RAM or by a DSP implemention of the scheme shown in Fig. 2, up to layer M–1.

Simulation results: A computer simulation was carried out in order to evaluate the performance of this approach. The modulator and demodulator filters (square-root of a raised-cosine) each have a roll-off factor a = 0.5 and are composed of $5Q$ taps. The oversampling factor Q is chosen as to be 3. Finally, the estimated models of g_T and HPA in Fig. 2 were assumed to be correct, i.e.

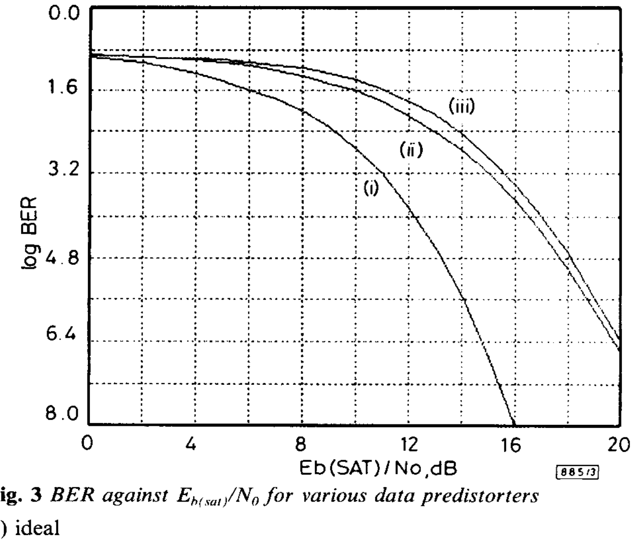

Fig. 3 *BER against $E_{b(sat)}/N_0$ for various data predistorters*

(i) ideal
(ii) C3_3_1, C3_5_1
(iii) global compensation

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$g'(t) = g_T(t)$ and $HPA' = HPA$. The transmission of 16-QAM complex signals with maximum input power to the HPA of –2dB has been considered. Two different complex predistorters have been tested on these signals: 'C3_3_1' is an MLP with three inputs, three nonlinear hidden neurons and one linear output neuron, and 'C3_5_1' is an MLP with three inputs, five nonlinear hidden neurons and one linear output neuron.

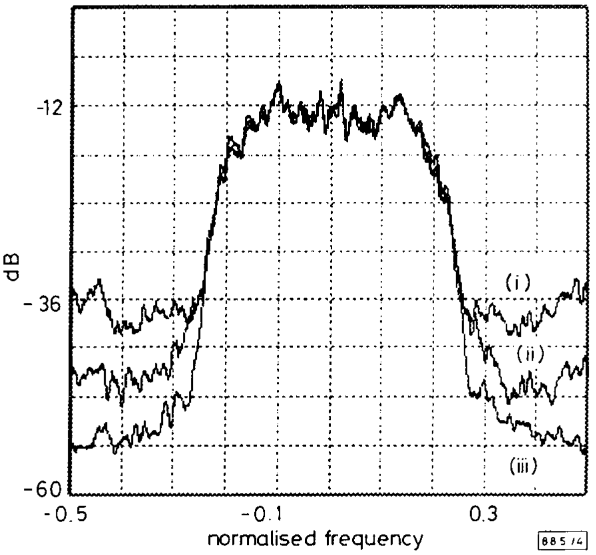

Fig. 4 *Power spectral density at output of HPA for various data predistorters*

(i) no predistorter
(ii) with predistorter
(iii) ideal

The graph of BER against signal-to-noise ratio at the output of the HPA, measured by $E_{b(sat)}/N_0$ as defined in [6], is shown in Fig. 3. At BER = 10^{-4} the performance is 3.2dB worse than the ideal case without an HPA. However, this result is 0.5dB better than that obtained by using the global compensation algorithm [2]. The effect of the HPA and various predistorters on the power spectral density (PSD) at the output of the HPA is shown in Fig. 4, where the frequency is measured with respect to the carrier frequency f_0. It is observed that the MLP approach produces a slightly better attenuation in the stopband than does the global compensation approach.

4 July 1996
Electronics Letters Online No: 19961279

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