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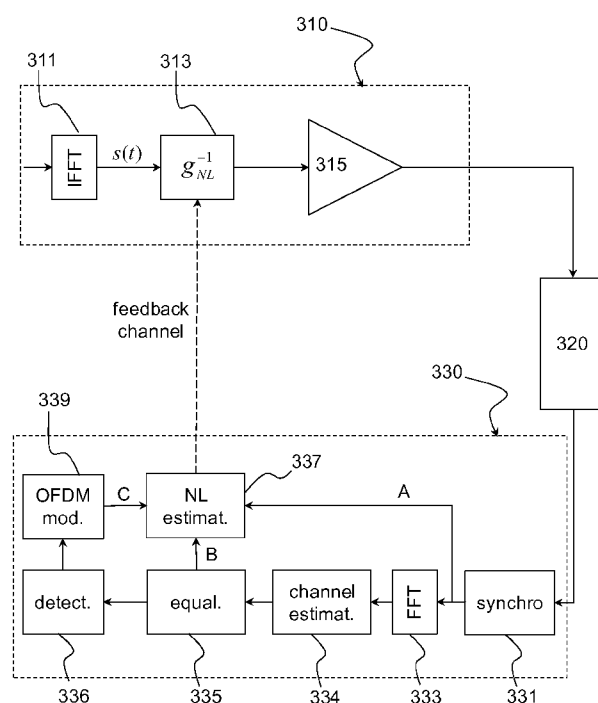
(57) Abstract: The present method mitigates a nonlinear effect in a communication system. A set of parameters describing the nonlinear effect is estimated at the receiving side and the estimated values are sent to the transmitter on a return channel. The transmitter uses these estimated values to predistort the signal upstream the stage where the non linear effect has occurred.

FIG. 3

GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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1

METHOD FOR PREDISTORTION IN A COMMUNICATION SYSTEM

TECHNICAL FIELD

5   The present application relates to the field of communication systems and can be applied to various communication standards, in particular to those using Orthogonal Frequency Division Multiplexing (OFDM) such as 802.11a, 802.11n, 802.16e, 3G-LTE, etc.

10

PRIOR ART

From a signal processing theoretical point of view, the communication systems are generally assumed to be linear. However, in practice, some components comprised in a communication system, either at the transmitter side, such as a power amplifier, or at the receiver side, such as a low noise amplifier (LNA), may exhibit non-linear characteristics. In such instance, the waveform of a signal transmitted by the transmitter and received by the receiver, is distorted if at least one of these components does not operate in its linear range. Due to this distortion, the reception of the transmitted symbols is degraded and the bit error rate (BER) is thus quite high. Furthermore, in case the communication system uses a plurality of frequency bands e.g. in an OFDM system a distortion of the signal in one frequency band may create a spectral regrowth in an adjacent frequency band (inter-band interference).

The problem of non-linear characteristics is particularly acute in OFDM systems since multi-carrier signals generally exhibit a high PAPR (Peak-to-Average-Power Ratio), in other words the signal waveforms have large amplitude variations. As the power amplifier is typically non-linear for large amplitudes, it may be necessary to decrease the output power in order to reduce the distortion. However, such reduction of the output power is detrimental to the signal-to-noise ratio at the reception. Alternatively, an A-class amplifier may be used at the expense of higher energy consumption and manufacturing costs.

For the reasons stated above, it is therefore essential to remove non-linear effects at large signal amplitudes.

The mitigation of non-linear effects in OFDM communication systems has been extensively investigated.

A first method for mitigating non-linear effects has been disclosed in US-A-6304140, where it is proposed to predistort the digital signal prior to its amplification. More specifically, a communication system implementing such a method is shown in Fig. 1. The signal at the output of the preamplifier 140 is down-converted to baseband by the mixer 150 and the baseband signal is sampled and digitized in ADC 160. The digital values thus obtained address a look-up table 110 in which are stored pre-measured calibration data. These data represent predistorted amplitude values which are converted into an analogue signal by

DAC converter 120, which is then up-converted by mixer 130 and amplified by preamplifier 140.

The look-up table may be either static or dynamic. In the latter case, the calibration is carried out at regular intervals and the calibration data are updated accordingly.

The predistortion method described above only mitigates non-linear characteristics of the amplifier and does not take into account non-linear effects possibly occurring downstream, *e.g.* at the receiving side. Furthermore, this predistortion method is complex, especially in case of adaptive predistortion, and therefore does not lend itself to an implementation in a mobile terminal, *i.e.* for an uplink. Even if implemented in a base station, *i.e.* for a downlink, the provision of additional components (fast feedback loop) increases the manufacturing costs of the transmitter.

A second method for mitigating non-linear effects has been disclosed in US2008/0032631, where it is proposed to compensate for non-linear effects occurring at the transmitter and/or the receiver.

More precisely, Fig. 2 represents a communication system implementing this method. The transmitter comprises an ADC converter, 220, a mixer, 230, and a preamplifier 240. At the receiving side, the signal is amplified in a low noise amplifier (LNA), 260, downconverted by the mixer 270 before being sampled and digitized in the DAC converter 280. The non linear effects incurred by the signal are estimated in module

4

295 (*e.g.* from a training sequence) and compensated for in module 290.

It is nevertheless difficult to compensate for the clipping of a signal or a saturation of the preamplifier after it has occurred. In such instance, the first method achieves better results.

There is therefore a need for a method mitigating the non-linear effects occurring in a communication system, both at the transmitter and the receiver, which does not require a complex implementation at the transmitter side and which can prevent clipping or saturation in a component.

DISCLOSURE OF THE INVENTION

The present invention is defined in the appended independent claims. Various advantageous embodiments are given in the dependent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be better understood from the description of the following embodiments, by way of illustration and in no way limitative thereto:

Fig. 1 represents a communication system implementing a known non-linearity predistortion method at the transmitting side;

Fig. 2 represents a communication system implementing a non-linearity compensation method at the receiving side;

Fig. 3 schematically shows an example of a communication system implementing a digital predistortion method according the invention;

Fig. 4A illustrates the AM-AM characteristics of a non-linear amplifier;

Fig. 4B illustrates a predistortion function for predistorting the amplitude of a signal prior to its amplification by the amplifier of fig. 4A;

Fig. 4C illustrates the AM-AM characteristics of the power amplifier of Fig. 4A when linearized by the predistortion function of Fig. 4B.

DETAILED DISCLOSURE OF PARTICULAR EMBODIMENTS

We will consider in the following a communication system comprising a transmitter at a source terminal, a transmission channel and a receiver at a destination terminal. The term "terminal" should be understood here in its broadest sense and may encompass either a base station or a relay station. The communication system comprises at least one non-linear component located at the transmitter of the source terminal or at the receiver of the destination. The invention also applies to a communication system comprising a plurality of non-linear components distributed along the transmission/reception chain. Examples of non-linear components are power amplifiers, mixers, variable gain amplifiers, low noise amplifiers, etc.

The invention equally applies to a communication system using a relayed channel. In such instance, the

6

communication system may be embodied by the transmitter
and the relay (acting as receiver) or the relay (acting
as transmitter) and the receiver. Alternatively, if the
relay is of the type "*Amplify and Forward*", namely if

5   the relay simply receives the signal, amplifies it and
resends it, the non-linear effects occurring in the
overall relayed channel may be taken into account by
the method according to the invention.

For the sake of illustration only and without
10   prejudice of generalization, we will assume in the
following that the communication system involves only
one non-linear component located at the transmitter of
the source terminal, namely a power amplifier. The man
skilled in the art will nevertheless understand that

15   the present method equally applies to other linear
effects occurring at the transmitter and/or the
receiver and/or over the channel (relayed or not).

More specifically, Fig. 3 illustrates an example
of an OFDM communication system applying a
20   predistortion method according to the invention.

The illustrated OFDM communication system
comprises a transmitter, 310, a transmission channel,
320, and a receiver, 330. The transmitter may comprise
various coding and modulation means (not shown),
25   depending upon the standard used, to generate
modulation symbols from information symbols. The
modulation symbols are then serial-to-parallel
converted (not shown) into blocks which are transformed
into the time domain by IFFT 311, as conventionally
30   known from the prior art. It will also be understood

7

than an OFDM symbol can be represented either by a block of modulation symbols in the frequency domain or by a sequence of samples in the time domain.

This signal obtained in the time domain is predistorted by predistorting means 313 before being amplified in power amplifier 315 and sent over the transmission channel 320.

At the receiving side, the signal is subjected to various processing steps according to the standard used. Typically, the receiver 330 may comprise a low noise amplifier (not shown), a mixer (not shown) for baseband down-conversion, an analogue-to-digital converter (not shown), synchronization means, 331, e.g. for determining the beginning of a frame or a sequence of symbols, an FFT module, 333, for transforming the OFDM symbols into the frequency domain, channel estimation means, 334, for estimating the channel coefficients, as known in the art. The channel coefficients are provided to the equalizer 335 for equalizing the received symbols. Finally, the information symbols are obtained from the symbols thus equalized via detection means 336.

Two variants can be envisaged for the channel estimation.

According to a first variant, a training sequence is appended as a preamble at the beginning of the frame of OFDM symbols carrying the payload. This training sequence is known by the receiver and designed to exhibit a low PAPR. Because of its low PAPR, the

8

training sequence experiences little non-linear effect (at least no NL effect due to saturation) and the channel coefficients can be estimated.

The training sequence can be generated directly in the time domain and inserted just after the IFFT module 311. Alternatively, it can be generated in the frequency domain, inserted before the IFFT module 311 and thereby converted into the time domain. If defined in the frequency domain, the training sequence may be constituted by a plurality of OFDM symbols, for example OFDM pilot symbols. We understand here by OFDM pilot symbol an OFDM symbol which has only pilot tones, *i.e.* an OFDM symbol for which the modulation symbols modulating the various sub-carriers are known to the receiver.

According to a second variant, pilot tones may be interspersed with modulation data in OFDM symbols. Such OFDM symbols comprising pilot tones are subjected to predistortion in 313, so as to be "linearized" at the receiver side. The channel coefficients can be estimated from the pilot tones thus received.

As explained further below in more detail, it is proposed to estimate the non-linear characteristics of the components located upstream the input of the non-linearity estimation means, 337, by using a training sequence as defined above.

More specifically, the non-linearity estimation means 337 may estimate said non-linear characteristics from a training sequence as output by synchronisation

means, 331, and FFT module, 333, before it is equalized (option represented by A).

Alternatively, if the training sequence is a sequence of pilot OFDM symbols, the non-linearity estimation means 337 may estimate said non-linear characteristics from said pilot OFDM symbols as output by the equalizer 335 (option represented by B).

Further alternatively, the estimation of the non-linearity can be decision-aided. In such instance, the training sequence is still a sequence of OFDM symbols, but the non-linearity estimation means 337 estimates said non-linear characteristics by OFDM re-modulating, in OFDM modulator 339, the information symbols (option presented by C) detected in 336 from the equalized OFDM symbols. The OFDM modulator 339 maps the detected information symbols into modulation symbols, S/P converts them into parallel blocks and transforms the blocks thus obtained back in the time domain. It is emphasized that the information symbols should be error-free. This can be checked by using an error correcting code (ECC) or a Cyclic Redundancy Check (CRC), well known in the art.

The non-linear characteristics are estimated as a list of parameters which is sent in digital form to the transmitter and provided to the predistortion means. It should be understood that, if g_{NL} is a function describing the non-linear effect, the list of parameters may define g_{NL} or its inverse, g_{NL}^{-1}, called the predistortion function, used for predistorting the

signal. The predistortion function can be calculated at the receiving side or at the transmitting side. In both cases, the predistortion function compensates for the non-linear effect induced by all the components located

5   between the predistortion means and the non-linearity estimation means, 337.

It will be appreciated that the estimation of the non linear-effect and the calculation of the predistortion function can be entirely carried out at

10 the receiving side. This is particularly advantageous in case the transmitter is a mobile terminal since the predistortion itself does not require a complex implementation.

The estimation of the non linear effect can be

15 performed periodically, or when the BER (Bit Error Rate) exceeds a given threshold, or on request from the transmitter, or when the transmission power has changed (e.g. due to a new power allocation). The parameters can be sent as a message at the physical level or

20 embedded in a PDU (Protocol Data Unit) of higher level.

Where the standard already provides for a message from the receiver to the transmitter, i.e. an uplink message (if the source is a mobile terminal and the destination is a base station) or a downlink message

25 (if the source is a base station and the destination is a mobile terminal), and if bits are available in this message, the parameters are preferably sent by using these bits. Otherwise, a specific predistortion information message coding these parameters can be

11

designed. Examples of predistortion information messages for some standards are given further below.

In general, the estimation of the non-linear effect is obtained from a training sequence.

5   According to an embodiment of the invention, the non-linear effect can be estimated from a sequence of N training OFDM symbols $P_0, \ldots, P_{N-1}$. These training symbols may be defined either in the frequency domain or in the time domain.

10   According to a first variant the training sequence is known a priori by the receiver. For example, the training sequence may be defined as:

$$\lambda_0 P_0, \lambda_1 P_0, \ldots, \lambda_{N-1} P_0 \qquad\qquad (1)$$

where P_0 is a pilot OFDM symbol and $\lambda_0, \ldots, \lambda_{N-1}$ are scalar
15   or complex values of distinct amplitudes. Preferably, the amplitudes thereof are chosen to span the whole range of the preamplifier. More preferably, $\lambda_n = a^n e^{i\varphi_n}$ for $0 \leq n \leq N-1$ where $a > 1$ is a scalar value.

As the receiver knows these symbols, it can
20   estimate how they are distorted. Whereas channel estimation accounts for the linear response of the transmission channel, the non-linear estimation accounts for the non-linear distortion of the transmitted signal. Non-linear estimation and channel
25   estimation can be performed in two distinct steps or in one single step. When they are preformed in two distinct steps, the non-linear estimation can be

carried directly on the training sequence or on the equalized training sequence.

According to a second variant, the non-linear estimation is decision-aided, namely it uses the information symbols decided by the detection means, 336 to generate the training OFDM symbols. Provided the information symbols are detected error-free these information symbols are mapped again into modulation symbols and these modulation symbols can be transformed into OFDM symbols (by S/P conversion as they ware at the transmitter). The sequence of OFDM symbols thus obtained is a training sequence which can be used as a reference for channel estimation and non-linear estimation (decision-aided estimation).

Whatever the variant, the non-linear effect can be estimated in the time domain or in the frequency domain according to one of the methods already described in US2008/0032631, the contents of which are incorporated herein by reference.

More specifically, if we denote s the signal at the input of power amplifier 315 and s_1 the signal at its output, prior to be sent over the transmission channel, we have, in the time domain:

$$s_1(t) = g\big(|s(t)|\big)s(t) \tag{2}$$

where g is the amplifier gain and $|s(t)|$ is the amplitude of the complex input signal $s(t)$. g is a function of the instantaneous amplitude of the input signal s. The gain

13

g may modify the amplitude and/or the phase of the input signal s in a non-linear way, introducing nonlinearities into the communication system, be it in the AM-AM characteristics, *i.e.* the curve of the output signal amplitude as a function of the input signal amplitude, and/or the AM-PM characteristics, *i.e.* the curve of the output signal phase as a function of the input signal amplitude.

In the frequency domain, S_1 is the result of the convolution between the gain G of the power amplifier and the input signal S:

$$S_1(f) = G(S(f)) \otimes S(f) \tag{3}$$

The amplified signal, S_1, is then transmitted by one or more antennas onto the transmission channel 320. The received signal S_2 can be expressed as:

$$S_2(f) = H(f)S_1(f) + \eta(f) \tag{4}$$

where H stands for the channel response in the frequency domain and η is an additive white gaussian noise.

The channel estimation conventionally obtains frequency response $H(f)$, or the corresponding impulse response $h(t)$ in the time domain. For doing, it may use pilot tones in OFDM symbols or pilot OFDM symbols as defined above.

14

The non-linearity estimation consists *e.g.* in determining interpolation points of the AM-AM characteristics and/or of the AM-PM characteristics of the power amplifier.

5   If we denote $x = |s(t)|$, the amplitude of the input signal and assume first that the gain function $g(x)$ is real, it can be expressed as a polynomial:

$$g(x) = g_0 + g_1 x + g_2 x^2 + \ldots + g_{M-1} x^{M-1} \qquad (5)$$

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where the coefficients $g_0, \ldots, g_{M-1}$ can be obtained by a training sequence $P_0, \ldots, P_{N-1}$.

g_0 being the linear gain of the power amplifier the actual gain can equivalently be expressed as:

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$$g(x) = g_0 g_{NL}(x) \qquad (6)$$

where $g_{NL}(x)$ is also a polynomial of degree $M-1$.

20   We assume now, that $s(t)$ represents a training sequence in the time domain. In practice this sequence is defined as a series of samples, the respective amplitudes and phases of which are known to the receiver.

25

Advantageously, the non-linear function $g_{NL}(x)$ is projected onto an orthonormal base of polynomials $p_0(x), p_1(x), \ldots, p_{M-1}(x)$, which spans an hyperplane of dimension M. In other words, the non-linear gain

30 function can be approximated as follows:

$$g_{NL}(x) = \alpha_0 p_0(x) + \alpha_1 p_1(x) + ... + \alpha_{M-1} p_{M-1}(x) \tag{7}$$

where $\langle p_m, p_{m'} \rangle = \delta_{m,m'}$, $\delta_{m,m'}$ being the Kronecker symbol and $\alpha_m = \langle g_{NL}, p_m \rangle$.

The dot product between two polynomials f and g is defined here as:

$$\langle f, g \rangle = \int_{[0,T]} f(|s(t)|) g(|s(t)|) dt \tag{8}$$

where $[0,T]$ is the time interval on which the training sequence is defined. The base of polynomials p_m, $m = 1,..,M-1$, can be obtained e.g. by the Gram-Schmidt orthonormalization algorithm, as known *per se*. It is important to note that the base of polynomials depends upon the training sequence. In the first variant, *i.e.* where the OFDM training symbols are known a *priori*, the coefficients of the polynomials can be pre-computed off-line and stored in a look-up table at the receiver side.

If we denote $y(t)$ the received signal in the time domain corresponding to the transmission of the training sequence, the non-linear characteristics can be obtained by projecting the amplitude of the received signal onto the orthonormal polynomials, namely by calculating the coefficients from the dot product:

$$\alpha_m = \int_{[0,T]} |\tilde{y}(t)| p_m(|s(t)|) dt \tag{9}$$

16

where $\tilde{y}(t)$ is the equalized received signal. Alternatively, the coefficients may be calculated from the received signal, before equalization:

$$\alpha'_m = \int_{[0,T]} |y(t)| p_m(|s(t)|) dt \qquad (10)$$

It should be noted that these coefficients take into account both the linear effect due to the channel (fading coefficients) and the non-linear effect incurred upstream.

More generally, the gain function is complex and can be approximated as follows:

$$g_{NL}(x) = \alpha_0 p_0(x) + \alpha_1 p_1(x) + ... + \alpha_{M-1} p_{M-1}(x) \exp\left(j\left(\beta_0 p_0(x) + \beta_1 p_1(x) + ... + \beta_{M-1} p_{M-1}(x)\right)\right)$$

$$(11)$$

where $\beta_m = \langle \arg(g_{NL}, p_m \rangle$.

The coefficients α_m and β_m can be estimated and sent to the transmitter. More specifically, the phase of the received signal $\arg(y(t))$ (equalized or not) is projected onto the set of polynomials $p(s(t))$ similar to (10). The amplitude predistortion function $f(x) = g_{NL}^{-1}(|x|)$ may be calculated at the transmitter side. Amplitude predistortion is applied at the input of the power amplifier and phase compensation is performed at the output thereof by multiplying the amplified signal with the coefficient $\exp(-\arg(g_{NL}(x)))$.

Instead of defining the non-linear function $g_{NL}(x)$ by a plurality of polynomial coefficients, it may alternatively be defined by plurality N of points of coordinates $(a_i, b_i \exp(jd_i))$ where $b_i \exp(jd_i) = g_{NL}(a_i)$. In such instance, the predistortion function $f(x)$ can be obtained as a sum of Lagrange polynomials:

$$f(x) = \sum_{i=1}^{N} L_i(x) \quad \text{where} \quad L_i(x) = a_i \prod_{j \neq i} \frac{x - b_j}{b_i - b_j} \tag{12}$$

It should be understood that f is an interpolation polynomial of degree $N-1$ such that $f(b_i) = a_i$ for $i = 1, \ldots, N$. In such instance, the coordinates $(a_i, b_i \exp(jd_i))$ are sent to the transmitter. As above, the complex coefficients $\exp(jd_i)$ are used to multiply the amplified signal so as to rectify the phase distortion introduced by the power amplifier.

By applying the amplitude predistortion to the input signal, the amplified signal at the output of the power amplifier is:

$$s_1(t) = g\big(f(|s(t)|)\big)s(t) = g_0 s(t)\exp(j\arg(g_{NL}(s(t)))) \tag{13}$$

and, after phase compensation by multiplication with $\exp(-j\arg(g_{NL}(s(t))))$:

$$\bar{s}_1(t) = g_0 s(t) \tag{14}$$

More generally, it will be understood that the amplitude predistortion applied at the transmitter side

18

can account for any non-linear effect affecting the amplitude of the signal downstream (*i.e.* not only the power amplifier). Similarly, phase compensation may be combined with phase predistortion to remove a non-

5   linear effect affecting the phase of the signal downstream.

Fig. 4A illustrates the AM-AM characteristics of a non-linear amplifier, e.g. the characteristics of the

10 power amplifier in Fig. 1. It is noted that the amplifier saturates when the normalized amplitude of the input signal *na* is larger than 1.
The amplitude compensation used in the prior art allows to compensate for the non-linear effect when *na*

15 is lower than 1. However, for *na* > 1, the amplitude information is lost. By contrast, it is possible to choose the predistortion function so that the predistorted signal remains in the unsaturated region.

20 Fig. 4B illustrates an example of predistortion function to be applied at the input of the amplifier.

Fig. 4C illustrates the characteristics of the power amplifier linearized by the predistortion

25 function.

As already mentioned above, the predistortion information, in the form *e.g.* of the weighting coefficients $\alpha_0,...,\alpha_{M-1}$ or the coordinates of the

30 interpolation points (a_i,b_i), are sent to the transmitter.

19

More generally the predistortion information contains a list of parameters describing the non-linear effect g_{NL} or its inverse, g_{NL}^{-1}.

This predistortion information can be included in already existing messages if the telecommunication standard of the system provides for a return channel, and if sufficient bits are left available in these messages. Alternatively, new messages dedicated to the predistortion information can be created.

Two examples of using existing messages will be given hereinafter.

The WiMAX 802.16e standard provides for a mechanism allowing a base station (BS) to schedule a feedback from a mobile station (MS). For so doing the BS sends a message "Feedback Polling IE" (IE: Information Element) to the MS. The MS replies by sending back a message "Feedback header". The MS may also send this message as unsolicited feedback. A detailed presentation of the standard IEEE 802.16e is available from the URL http://standards.ieee.org.

The BS requests the MS to perform an estimation of the nonlinear effect by sending a specific message "Feedback Polling IE" *e.g.* with a "Feedback type" having a value larger than 14 (1110b).

Upon receiving such a message, the MS estimates the parameters describing the non-linear and sends the predistortion information to the BS via a "Feedback header" message.

20

The BS uses the predistortion information to predistort the signal before transmission over the downlink transmission channel.

5   The 3GPP project LTE (Long Term Evolution) as described in the specification 3GG TS 36.212 V9.0.0 downloadable from the 3GPP website http://www.3gpp.org provides the possibility for the base station (resp. the mobile station) to request the channel quality
10   information of downlink (resp. uplink) channel by sending a DCI (downlink control information) message.

By adding a new format of the DCI message dedicated to non-linear estimation, the BS (resp. the
15   MS) may request from the MS (resp. the BS) to estimate the parameters describing the non-linear effect. The predistortion information thus obtained can be sent over the feedback channel as a feedback message, for example as part of a HARQ-ACK message.

20   The man skilled in the art will understand that the present invention is not restricted to the above-described embodiments and examples and that, on the contrary, further embodiments can be contemplated within the scope of the claims appended hereto.

25

CLAIMS

1. Method for mitigating a nonlinear effect affecting an OFDM communication system, which includes a transmitter, a transmission channel and a receiver, comprising:

- estimating at the receiver a set of parameters describing said nonlinear effect, from a training sequence received at the receiver and distorted by said nonlinear effect;

- transmitting the estimated values of said parameters back to said transmitter over a return channel;

- predistorting at the transmitter a signal to be sent to the receiver by using said estimated values of said parameters.

2. Method according to claim 1, characterized in that said training sequence is constituted by a plurality of training symbols $\lambda_0 P_0$, $\lambda_1 P_0$, ..., $\lambda_{N-1} P_0$, where P_0 is an OFDM pilot symbol and $\lambda_0,...,\lambda_{N-1}$ are scalar or complex value having distinct amplitudes.

3. Method according to claim 2, characterized in that $\lambda_n = a^n e^{i\varphi_n}$ for $0 \leq n \leq N-1$ where $a > 1$ is a scalar value, φ_n are phase values.

4. Method according to claim 1, characterized in that the training sequence is constituted by a plurality of training OFDM symbols obtained by

detecting information symbols at the receiver, and
provided they are error-free, mapping them into
modulation symbols and transforming them back into OFDM
symbols.

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5. Method according to any of claims 1 to 4,
characterized in that the set of parameters comprises a
plurality M of first coefficients $\alpha_0, ..., \alpha_{M-1}$ such that:

$$g_{NL}(x) = \alpha_0 p_0(x) + \alpha_1 p_1(x) + ... + \alpha_{M-1} p_{M-1}(x)$$

10   where $g_{NL}(x)$ is a real function describing the nonlinear
effect in relation with the amplitude x of the signal
and $p_0(x), ..., p_{M-1}(x)$ is a plurality M of orthonormal
polynomials.

15   6. Method according to claim 5, characterized
in that said each first coefficient (α_m) related to a
polynomial (p_m) is obtained by calculating a dot
product between a signal representing the training
sequence, distorted by said polynomial, and the signal
20   actually received by the receiver when said sequence is
transmitted $(y(t))$.

7. Method according to claim 5 or 6,
characterized in that the predistortion of a signal $s(t)$
25   is carried out at the transmitter by multiplying said
signal with $g_{NL}^{-1}(|s(t)|)$ prior to the occurrence of said non
linear effect.

8. Method according to any claims 1 to 4, characterized in that the set of parameters comprises a plurality M of first coefficients $\alpha_0,...,\alpha_{M-1}$, and a same plurality of second coefficents $\beta_0,...,\beta_{M-1}$ calculated so that:

$$g_{NL}(x) = \left[\alpha_0 p_0(x) + ... + \alpha_{M-1} p_{M-1}(x)\right]$$
$$\times \exp(j\left[\beta_0 p_0(x) + ... + \beta_{M-1} p_{M-1}(x)\right])$$

where g_{NL} is a complex function describing the nonlinear effect in relation with the amplitude x of the signal and $p_0(x),...,p_{M-1}(x)$ is a plurality M of orthonormal polynomials.

9. Method according to claim 8, characterized in that the predistortion of a signal $s(t)$ is carried out at the transmitter by multiplying said signal with $g_{NL}^{-1}(|s(t)|)$ prior to the occurrence of said non linear effect and by multiplying thereafter the signal with a phase compensation term $\exp(-j\left[\beta_0 p_0(x) + ... + \beta_{M-1} p_{M-1}(x)\right])$.

10. Method according to any of claims 1 to 4, characterized in that the set of parameters comprises the coordinates of interpolation points of $g_{NL}(x)$ or its inverse $g_{NL}^{-1}(x)$, where $g_{NL}(x)$ is a function describing the nonlinear effect in relation with the amplitude x of the signal.

11. Method according to any preceding claim, characterized in that the communication system is in

24

conformity with the Wi-MAX 802.16e standard and that an estimation of the nonlinear effect is requested from a base station to a mobile station by sending thereto a "Feedback Polling IE" message with a "Feedback type" having a value larger than 14 (1110b).

12. Method according to claim 11, characterized in that the mobile station sends the predistortion parameters to the base station in a "Feedback header" message.

13. Method according to any of claims 1 to 10, characterized in that the communication system is in conformity with the 3GG TS 36.212 specification and that a base (resp. a mobile) station requests from a mobile (resp. a base) station an estimation of the linear effect by sending thereto a DCI message.

14. Method according to claim 13, characterized in that the mobile (resp. the base) station sends the predistortion parameters in a feedback message.

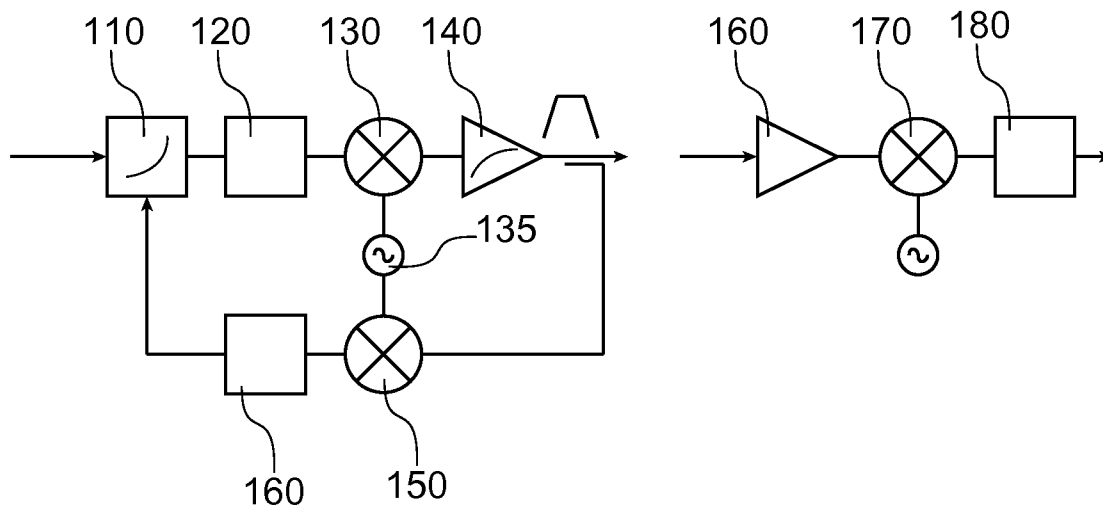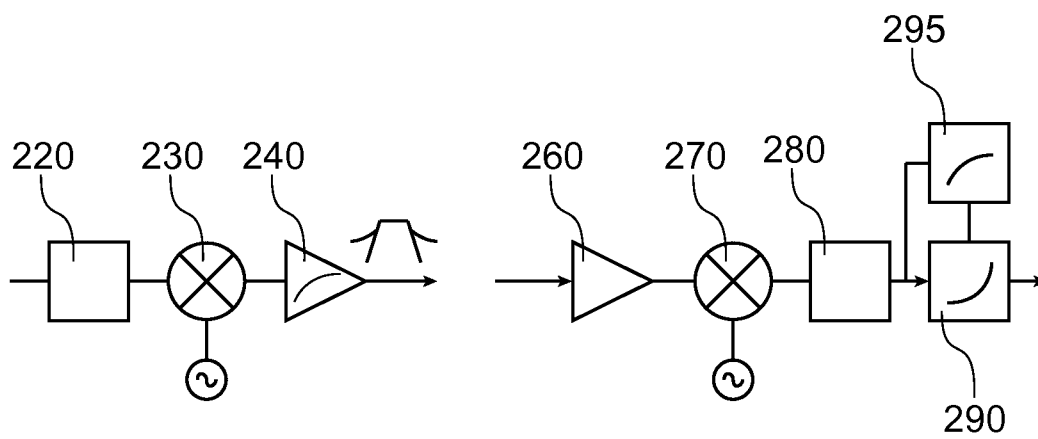15. Method according to claim 14, characterized in that the feedback message is an HARQ-ACK message.

FIG. 1

FIG. 2

FIG. 3
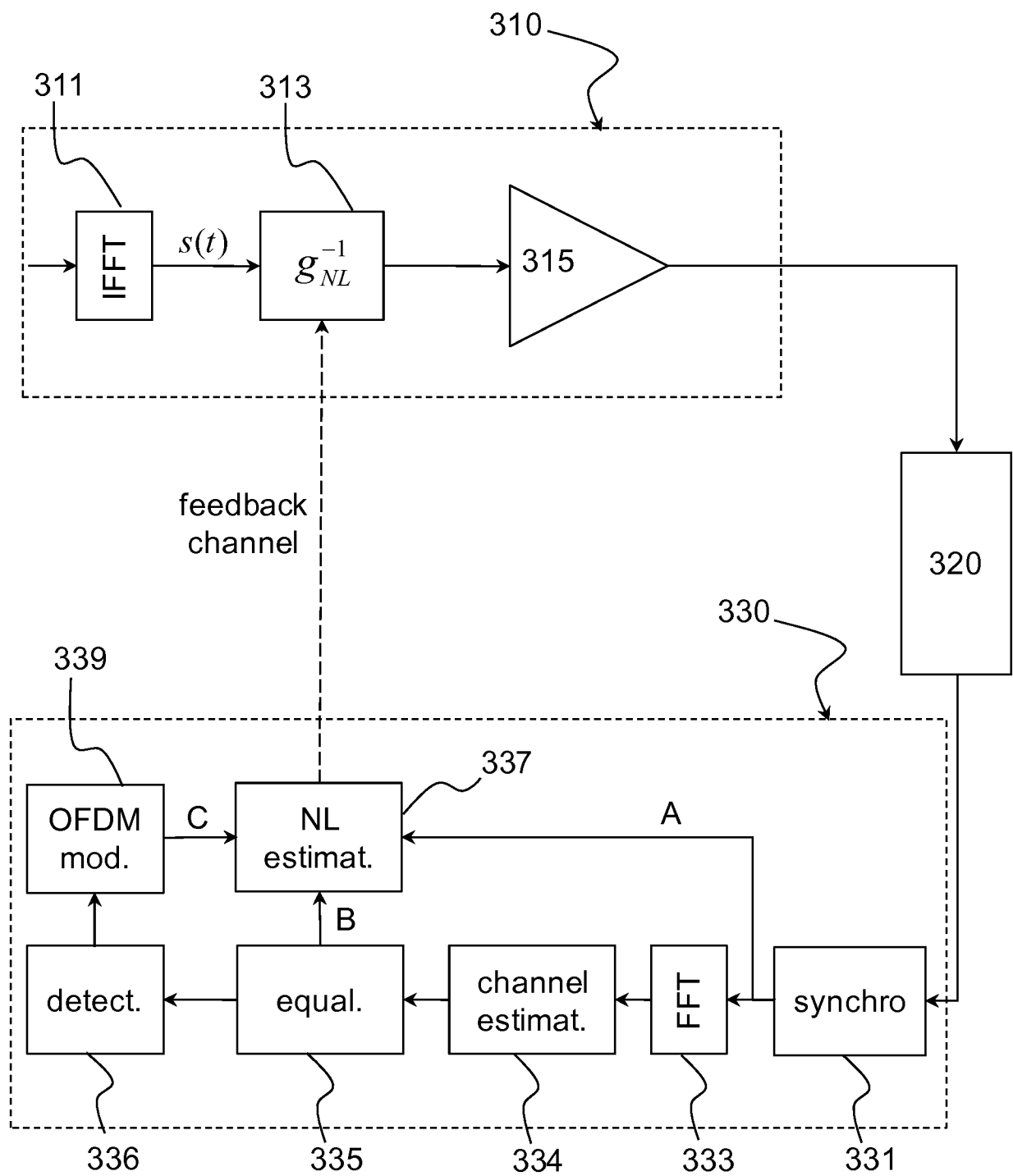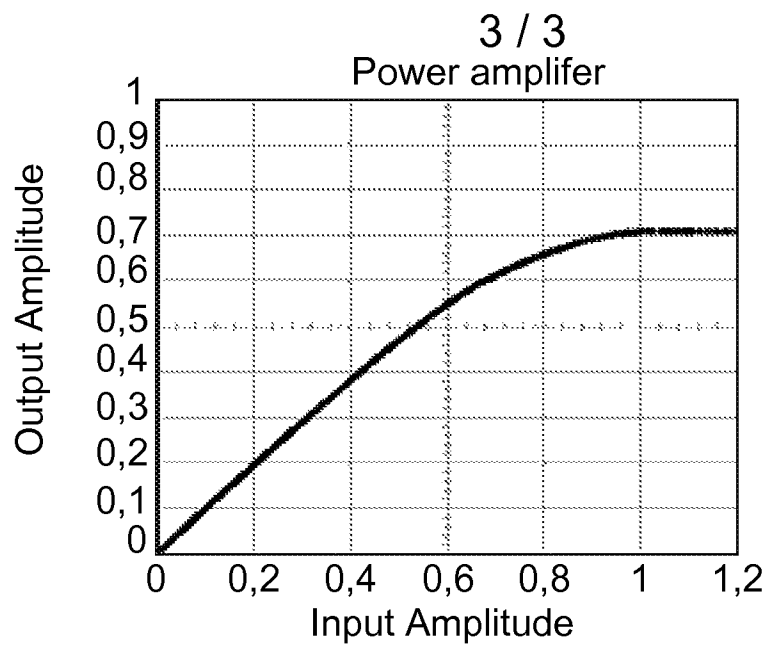
FIG. 4A
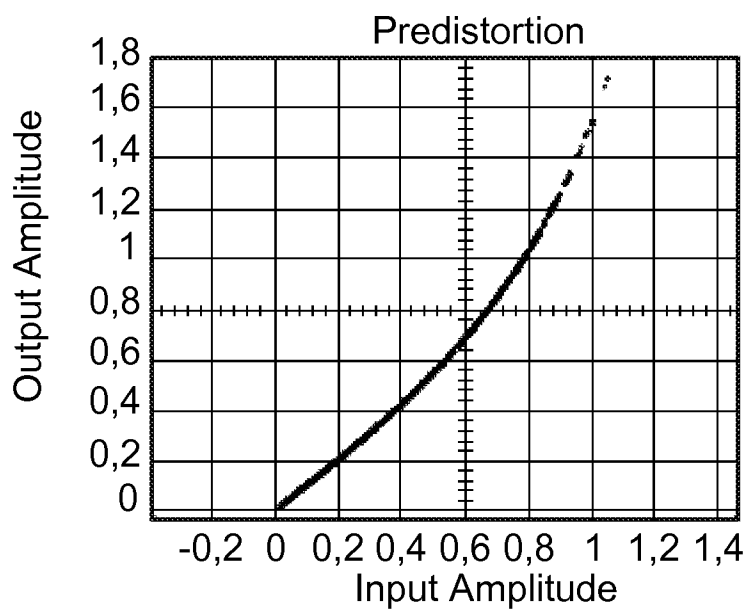
FIG. 4B

FIG. 4C

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L27/36   H03F1/32
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04L H03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, COMPENDEX, INSPEC, IBM-TDB, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 117 115 A1 (NOKIA SIEMENS NETWORKS SPA [IT]; NOKIA SIEMENS NETWORKS OY [FI]) 11 November 2009 (2009-11-11) paragraph [0002] paragraph [0025] - paragraph [0026] figure 5 -----	1,11-15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 April 2011	13/07/2011

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Farese, Luca

Form PCT/ISA/210 (second sheet) (April 2005)

1

INTERNATIONAL SEARCH REPORT

Box No. II   Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such
   an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III   Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

        see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable
   claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of
   additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers
   only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is
   restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

        1-3, 11-15

Remark on Protest   ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the
                             payment of a protest fee.

                          ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest
                             fee was not paid within the time limit specified in the invitation.

                          ☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (2)) (April 2005)

FURTHER INFORMATION CONTINUED FROM   PCT/ISA/ 210

This International Searching Authority found multiple (groups of)
inventions in this international application, as follows:

    1. claims: 1-3, 11-15

        Amplitude values of the training symbols
               ---

    2. claim: 4

        Remodulation of detected OFDM symbols
               ---

    3. claims: 5-10

        Characterization of the non-linearity

INTERNATIONAL SEARCH REPORT
Information on patent family members

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2117115 A1	11-11-2009	NONE	