

LOW COMPLEXITY TEMPORAL SYNCHRONIZATION IN A DIGITAL PREDISTORTION CALCULATION LOOP

The invention lies in the field of communications in general, whether
5 involving wired communications or radio communications, when the signal to
be emitted has to be amplified by a nonlinear amplifier whose non-linearities
are compensated by a digital predistortion mechanism.

In order to comply with the link budget required for a communication, it
10 is necessary to amplify the signal to be transmitted. This amplification is
generally done with the aid of an analog power amplifier. There exists a
compromise in the design or the choice of a power amplifier called the
efficiency/linearity compromise: the more significant the linearity of an
amplifier, the worse the power efficiency of this amplifier, and vice versa.
15 Stated otherwise, the more linear the amplifier, the more power it consumes.

Moreover, there exist two large families of signals to be transmitted:

- So-called constant-envelope signals. These signals have the
property of having an instantaneous power which is constant as
a function of time. For signals of this type, it is customary to use
20 amplifiers with very high efficiencies whose low linearity does not
disturb the spectrum of the signal at the amplifier output.
- So-called non-constant-envelope signals. These signals have the
property of having a more or less significant variation of the
instantaneous power as a function of time. For these types of
25 signals, the linearity of the amplification step is decisive since it
greatly impacts the spectrum of the signal at the amplifier output.
Indeed, the signal output by the power amplifier must in general
comply with a more or less constraining spectral mask, so as not
to jam the channels that are not used by the transmission. It is
30 then ordinarily necessary to use very linear power amplifiers
whose efficiency is poor.

To reduce the spectral regrowths related to the non-linearities of the power amplifier, in particular when transmitting signals with non-constant envelope, it is known to modify the modulated signal to be transmitted in such a way as to pre-compensate the deformations applied by the power amplifier. This method is known by the name predistortion linearization. This predistortion may be analog or digital. The invention falls within the framework of digital predistortion. Predistortion consists in applying a non-linearity upstream of the power amplifier in such a way that the association of the non-linearity of the linearization with the power amplifier corresponds to a linear system. It is thus possible to use a power amplifier having better efficiency, while tolerating the associated non-linearity since the latter is assumed to be pre-compensated by the linearization method. There exist numerous algorithms for digital predistortion, which are more or less complex and more or less efficacious. One of them, named GMP (English acronym standing for Generalized Memory Polynomial), is described in detail in the article D.R. Morgan, Z. Ma, J. Kim, M. G. Zierdt et J. Pastalan, "A Generalized Memory Polynomial Model for Digital Predistortion of RF Power Amplifiers", IEEE Transactions on Signal Processing, vol. 54, no. 10, pp. 3852-3860, Oct. 2006.

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The method of linearization by digital predistortion requires the knowledge of the behaviour of the power amplifier. This knowledge is in general obtained by having baseband versions of the signals at the power amplifier input/output.

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Figure 1a describes the main elements of a transmission apparatus according to the prior art not implementing any predistortion.

In Figure 1a, the digitized and modulated signal to be transmitted is oversampled 101 and then converted into an analog signal by a digital-analog converter (or DAC) 102 and amplified by a power amplifier 103 before being emitted. Figure 1a, just like the other figures, does not represent the steps which are well known to the person skilled in the art and not necessary for understanding the invention, viz. for example the transposition of the

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analog signal to carrier frequency, or the various successive steps of filtering of the analog signal, of amplification, or of attenuation when this is the case.

It is the non-linearities of the amplifier 103 which alter the signal to be transmitted and create spectral regrowths in the emitted signal.

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Figure 1b describes the main elements of a transmission apparatus according to the prior art implementing digital predistortion of the signal. Accordingly, a predistortion calculation loop 110 is added to the transmission chain of Figure 1a, the object of which is to calculate the coefficients of a predistortion 111 applied to the signal to be transmitted. The predistortion calculation loop takes as inputs the signal emitted after amplification and the predistorted signal (or the signal to be transmitted), so as to calculate the coefficients of the predistortion 111.

In the representation of Figure 1b, the predistortion calculation loop comprises the conversion of the signal emitted into a digital signal by an analog-digital converter (or ADC) 112, and then its downsampling 113. The downsampled signal and the predistorted signal are synchronized temporally 114, in such a way that they can be compared in order to calculate 115 the predistortion coefficients to be applied to the signal to be transmitted. The resynchronization consists in advancing or delaying one of the two signals as a function of the group propagation time so as to be able to compare them. When the resynchronized downsampled signal and signal to be transmitted are equal, then the predistortion perfectly compensates the non-linearities of the amplifier.

The data are transmitted by blocks of consecutive samples or else continuously. The calculation of the predistortion coefficients can then likewise be carried out by data blocks or continuously.

The representation of Figure 1b, as well as that presented later for Figure 2, is the representation most generally envisaged on account of its simplicity and its low cost of implementation. Numerous variations can be applied to it, which will appear obvious to the person skilled in the art and will not modify the predistortion performance. In particular, the predistortion calculation loop knowing the coefficients applied during predistortion 111, the

signal to be transmitted can be used as input of this loop instead of the predistorted signal. Likewise, the predistortion can be applied after the oversampling of the signal, this having no effect on predistortion performance but increasing the complexity of implementation. Finally, the predistortion calculation loop can take as inputs the predistorted signal after oversampling and the signal emitted digitized before downsampling, here again this having an impact on the complexity of implementation but not on performance. Hereinafter, it will be considered, in a nonlimiting manner and by way of illustration only, that the predistortion calculation loop takes as inputs the predistorted signal before oversampling and the signal emitted after downsampling.

The temporal desynchronization between the downsampled signal and the predistorted signal (or the signal to be transmitted) stems from the propagation times of the digital and analog functions. On completion of the time-synchronization step, the two signals must be perfectly synchronized temporally so as to be compared thereafter. Indeed, the least residual time offset between the two signals is interpreted as a defect due to the power amplifier, and is taken into account during the calculation of the predistortion coefficients. The predistortion then applies distortions to the signal to be transmitted, which do not correspond to the degradations of the amplifier and which may degrade the spectrum of the emitted signal.

This time-synchronization step, and in particular the choice of the instant of sampling in the downsampler, is therefore a key function upon which the performance of the predistortion algorithm rests and which conditions the choice of the power amplifier.

In the prior art, there exist three large families of solutions making it possible to carry out the time-synchronization between the predistorted signal and the downsampled emitted signal.

The first solution consists in coarsely synchronizing the signals by using a precalculated and fixed sampling instant, by considering that the group propagation time of the signal is deterministic and invariant over time. This

sampling instant can be calculated theoretically on the basis of the group times of each of the analog and digital components, or measured using a calibration signal. Though the group time can be considered to be deterministic and invariant over time as regards the digital elements, this is not true as regards the analog part, where the responses of the components, and therefore the group propagation time, varies as a function of the age of the components, of the temperature and of the working frequency. This time-synchronization solution is therefore not optimal: the calculated predistortion coefficients will not make it possible to fully exploit the linearization capability.

The second solution consists in determining the offset between the signals by way of correlations carried out in the downsampled domain, that is to say before the oversampler 101 and after the downsampler 113. The problem with this technique is that the downsampling of the signals in the predistortion loop is not synchronized with the oversampling of the signals to be transmitted, there therefore exists a fractional delay, less than the duration of a sample, which degrades the quality of the predistortion. It is this fractional delay which it is important to estimate and to compensate. One of the possibilities is then to implement complex techniques for interpolating the results of the correlation so as to have results whose precision is less than a sample. The precision of the correlation increasing with the length of the sequences, the correlated sequences must be of significant length. Moreover, resynchronization of the signals is then complex since it necessitates the interpolation of the signals to be resynchronized in order to compensate the fractional delay. All this is therefore complex to implement and a significant impact on the cost of implementation of the predistortion algorithm.

The third solution consists in carrying out the correlations of the second solution on signals taken in the oversampled domain, that is to say after the oversampler 101 and before the downsampler 113. If the precision arising therefrom is significant, the correlators required are of significant size, this being very expensive in terms of complexity of the calculations.

There is therefore a need for a procedure making it possible to finely synchronize the signals in a predistortion algorithm, and whose complexity of implementation is limited.

5 To address the technical problem of the complexity of the resynchronization operations required in the predistortion chains of signal transmission rigs while offering the best possible performance, the invention describes an apparatus and method for temporally synchronizing two signals in a predistortion calculation loop, in which the time-synchronization
10 comprises two parts:

- a first, coarse, part in which the offset applied is a coarse offset. This first offset can for example be calculated theoretically on the basis of the elements of the emission chain, be measured in the factory or on the rig, or be calculated by carrying out the correlation between the two signals, and

15 - a second, fine, part in which the offset applied is calculated on the basis of the predistortion coefficients applied to the signal before its emission.

This second part makes it possible to finely correct the offsets, with a precision of less than the duration of a sample in the downsampled domain, and to follow the variations of the group time of the emission chain that are
20 related to the aging of the components, to the variations of the carrier frequency or of the temperature.

With respect to the prior art, this solution has furthermore the advantage of being very simple to implement and inexpensive in terms of calculations.

25 It exhibits particular interest for radio-frequency signals of single-carrier type with non-constant envelope, but above all for modulations of multi-carrier type, which belong to the family of signals with non-constant envelope. Indeed, these signals generally exhibit significant amplitude variations, thus rendering them very sensitive to the non-linearities of power
30 amplifiers. For example, High Frequency military radiocommunications links offer a beyond line of sight (BLOS) transmission capability which relies on the reflection properties of the atmospheric layers, thus allowing them to carry out long-distance or indeed very long-distance communications without

requiring recourse to a satellite link or relay stations. These links transmit signals with non-constant envelope over very significant distances. The efficiency of the power amplifier is therefore paramount for communications of this type. The implementation of the most precise possible predistortion
5 procedure is one of the means which make it possible to achieve the range objectives envisaged.

However, the invention applies in a totally identical manner, whatever the type of signal transmitted and the transmission medium. It can thus be implemented for example within the framework of fibre optic transmissions.

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For this purpose, the invention describes a method for temporally synchronizing two signals in a signal transmission device. The two synchronized signals are used by a predistortion calculation loop to calculate predistortion coefficients applied to the signal to be transmitted before its
15 amplification and its emission. The method according to the invention comprises consecutively:

- the application, to one of the two compared signals, of a first time offset corresponding substantially to the time gap between the two signals, and

- 20 - the application, to one of the two compared signals, of a second time offset corresponding substantially to the time gap between the two signals after application of the first time offset, the second time offset being calculated on the basis of the said predistortion coefficients.

25 The first offset corresponds to a coarse offset, either calculated theoretically, or measured on the basis of a calibration signal, or obtained by correlation between the two signals to be temporally synchronized, or by any other means known to the person skilled in the art.

30 According to one embodiment of the invention, the two signals to be temporally synchronized are:

- a first signal corresponding to the signal to be transmitted before or after application of the predistortion,
- a second signal corresponding to the emitted signal.

5 Advantageously, the second time offset is calculated on the basis of the predistortion coefficients which are expressed linearly as a function of the signal to be transmitted.

10 According to one embodiment, in particular when the predistortion algorithm implemented is an algorithm of GMP type, the second time offset Δt equals:

$$\Delta t = -Real \left[\frac{\sum_{l=0}^{L_a-1} l \cdot a_{0,l}}{\sum_{l=0}^{L_a-1} a_{0,l}} \right],$$

where $a_{0,l}$ represents L_a predistortion coefficients expressed linearly as a function of the signal to be transmitted, and $Real(X)$ the real part of the complex number X .

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According to one embodiment, in particular when the predistortion algorithm implemented is an algorithm of DVR type, the second time offset Δt equals:

$$\Delta_t = -Real \left[\frac{\sum_{l=0}^M l \cdot a_l}{\sum_{l=0}^M a_l} \right],$$

20 where a_l represents M predistortion coefficients expressed linearly as a function of the signal to be transmitted, and $Real(X)$ the real part of the complex number X .

25 Advantageously, the processings carried out by the predistortion calculation loop comprise the downsampling of the signal emitted, the second time offset being applied before this downsampling.

The invention also describes a signal transmission device comprising a predistortion calculation loop for calculating predistortion coefficients applied to the signal to be transmitted, and an amplifier for amplifying and emitting
5 the predistorted signal. The device furthermore comprises:

- a means for applying a first time offset, of two signals used by the predistortion calculation loop, configured to compensate substantially and coarsely the time gap between the two signals, and

- a means for applying a second time offset of the two signals used by
10 the predistortion calculation loop, configured to compensate substantially and finely the time gap between the two signals after application of the first time offset, the second time offset being calculated on the basis of the said predistortion coefficients.

Description

The invention will be better understood and other characteristics and advantages will be better apparent on reading the description which follows, given without limiting effect, and by virtue of the appended figures among which:

- Figure 1a describes the main elements of a transmission apparatus according to the prior art not implementing any predistortion;
- 10 • Figure 1b describes the main elements of a transmission apparatus according to the prior art implementing a digital predistortion of the signal;
- Figure 2 describes the main elements of a signal transmission apparatus comprising a device for predistorting the power amplifier according to one embodiment of the invention;
- 15 • Figures 3a and 3b are representations, given by way of illustration, of signals which are resynchronized respectively without implementing and by implementing the invention;
- Figure 4 is a representation in the form of a state chart of the steps of an embodiment of the method of time synchronization according to the invention.
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Figure 2 describes the main elements of a signal transmission apparatus comprising a device for predistorting the power amplifier according to one embodiment of the invention.

25 This embodiment comprises the whole set of elements of the transmission chain according to the prior art described in Figure 1b. In particular, it implements a so-called coarse time-synchronization mechanism 114.

This mechanism is carried out according to the known procedures of
30 the prior art, such as for example:

- by characterization of the group time of the transmission chain and of the predistortion calculation loop, using the mean group times of each of the digital and analog elements of which it is composed;
- 5 - by measurement of the group time of the transmission chain and of the predistortion calculation loop, using for example a particular signal such as a Dirac and by measuring the offset in position of this Dirac on the predistorted signal and the downsampled emitted signal;
- 10 - by correlations between the predistorted signal and the emitted signal, undertaken in the downsampled domain, on sequences of reasonable size so as not to be too expensive implementationally.

The aim of the first time-synchronization mechanism is to compensate
 15 the biggest of the time offset between the two signals to be synchronized. The total group propagation time (from emission to reception) generally being very large in relation to the predistortion estimation capability, it is expected of the first synchronization mechanism that it offers sufficient precision to be able to calculate the coefficients of the predistortion, and not that it makes it
 20 possible to achieve the optimal performance of the predistortion algorithm. This is why one speaks of coarse time-synchronization substantially correcting the offset between the signals. In practice, the expected precision of this first synchronization is that it allows registration of the signals to within a few samples, and preferably to within plus or minus one sample, at the
 25 sample tempo of the signals which reach it.

The predistortion chain 201 of this embodiment furthermore comprises a so-called fine time-synchronization mechanism 202.

The aim of the fine time-synchronization mechanism is to correct the residual time gap between the two signals after compensation of the coarse
 30 time offset. The precision expected by the fine time-synchronization is less than the duration of a sample in the downsampled domain. In contradistinction to the coarse synchronization, the fine synchronization is not based on an analysis of the signals but on the coefficients of the predistortion. Thus, the predistortion calculation loop 201 comprises a

module for analyzing the coefficients 203, which takes as input the coefficients calculated by the module 115 to determine the offset that has to be applied by the fine synchronization to the digitized emitted signal. This offset being dependent on that applied by the coarse synchronization, it may
5 involve a delay or an advance.

The choice of the location where the fine synchronization in the predistortion calculation loop is performed has no effect on the predistortion performance. Indeed, it can be situated either before or after the downsampler 113, or even be situated after the coarse time-synchronization.
10 However, the fine synchronization is aimed at offsetting the signals with a granularity of less than the sample time in the downsampled domain. If it is carried out after the downsampling 113, it is then necessary to interpolate the signals so as to advance them or delay them, and this may be expensive in terms of calculations to be carried out. If it is carried out before the
15 downsampler 113, it then requires only the implementation of an advance line or a delay line. Its cost of implementation is therefore lower when it is carried out before the downsampling of the emitted signal, as is the case in the embodiment represented in Figure 2.

20 In order to calculate the offset that has to be applied by the fine time-synchronization 202, the invention relies on the specific features of the linearization. Indeed, apart from for very narrow-band applications, or else for very relaxed specifications in respect of linearities and out-of-band emissions, the linearization method must take account of the power
25 amplifier's memory effects. The coefficients of the predistortion therefore intrinsically have a time dimension when the memory effects are considered. Consequently, the temporal information in respect of synchronization is available in these coefficients.

Taking the amplifier's memory effects into account in the predistortion
30 coefficients allows the algorithm to partly compensate the lack of precision of the coarse time-synchronization. The synchronization information present in the coefficients is then more precise than the initial synchronization.

There exist numerous algorithms for digital predistortion of a signal (Digital Pre-Distortion, or DPD in English), which take into account the memory effects of the power amplifier. Most, such as for example the MP (Memory Polynomial in English), GMP, DDR (Dynamic Deviation Reduction in English) and VS (Volterra Series) algorithms, model the non-linearities of the amplifier by a polynomial model. This polynomial model is expressed by coefficients that may be classed into two categories:

- linear coefficients, which are expressed in a linear manner with respect to the input, and
- nonlinear coefficients.

The nonlinear coefficients act in particular on the spectral regrowths away from the carrier frequency, generally at very low power levels. Conversely, the effects of the time-synchronization offsets are predominantly borne by the linear coefficients of the predistortion.

The invention therefore makes the simplifying assumption that the effect of the time offset is borne by the linear coefficients alone. Hereinafter, the GMP algorithm is used by way of example to illustrate the calculation of the offset on the basis of predistortion coefficients, but the invention applies in an equivalent manner whatever predistortion algorithm is used, provided it is expressed according to a model that takes memory effects into account.

In GMP, the predistorted signal $y(n)$, resulting from the predistortion of the signal to be transmitted $x(n)$, can be expressed in the following manner as a function of the coefficients $a_{k,l}$, $b_{k,l,m}$, $c_{k,l,m}$:

$$\begin{aligned}
 y(n) = & \sum_{k=0}^{K_a-1} \sum_{l=0}^{L_a-1} a_{k,l} x(n-l) |x(n-l)|^k \\
 & + \sum_{k=1}^{K_b} \sum_{l=0}^{L_b-1} \sum_{m=1}^{M_b} b_{k,l,m} x(n-l) |x(n-l-m)|^k \\
 & + \sum_{k=1}^{K_c} \sum_{l=0}^{L_c-1} \sum_{m=1}^{M_c} c_{k,l,m} x(n-l) |x(n-l+m)|^k
 \end{aligned} \tag{1}$$

The coefficients $a_{k,l}$, $b_{k,l,m}$, and $c_{k,l,m}$ are calculated by the module 115. They can be obtained, for example, using the least squares procedure.

In the proposed approach, only the linear terms are preserved, that is to say, for GMP, the L_a coefficients $a_{k,l}$ for $k = 0$, which corresponds to the coefficients of type "A" (first line of equation (1)) of the GMP algorithm. Indeed, the L_a coefficients $a_{k,l}$ for $k = 0$ are the only ones which vary linearly as a function of the signal $x(n)$ to be transmitted, the other coefficients corresponding to nonlinear terms. Thus, equation (1) can be simplified into:

$$y(n) = \sum_{l=0}^{L_a-1} a_{0,l} \cdot x(n-l). \quad (2)$$

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To deduce therefrom the offset Δt , the Z-transform of equation (2) is calculated, i.e.:

$$H(Z) = \sum_{l=0}^{L_a-1} Z^{-l} \cdot a_{0,l}. \quad (3)$$

The normalized angular frequency response $\omega_n = \omega/f_{DPD}$ (with f_{DPD} the sampling frequency at which the predistortion operates) is obtained by replacing the Z operator with $e^{j\omega_n}$:

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$$H(e^{j\omega_n}) = \sum_{l=0}^{L_a-1} e^{-j\omega_n l} \cdot a_{0,l}. \quad (4)$$

The sought-after delay Δ_t corresponds to the opposite of the group propagation time GPT :

$$\Delta_t = -GPT \Big|_{\omega_n=0} = \frac{d \left(\text{Arg}[H(e^{j\omega_n})] \right)}{d \omega_n} \Big|_{\omega_n=0}, \quad (5)$$

20 with $\text{Arg}[X]$ the argument of X .

The relation connecting the Napierian logarithm of a complex number and its argument is:

$$\ln(x) = \ln|x| + j \cdot \text{Arg}[x]. \quad (6)$$

The delay is then expressed in the following manner:

$$\begin{aligned} \Delta_t &= \left. \frac{d \left(\text{Arg}[H(e^{j\omega_n})] \right)}{d \omega_n} \right|_{\omega_n=0} \\ &= \left. \frac{d \left(\text{Imag} \left[\ln \left(H(e^{j\omega_n}) \right) \right] \right)}{d \omega_n} \right|_{\omega_n=0} \\ &= \text{Imag} \left[\left. \frac{d \left(\ln \left(H(e^{j\omega_n}) \right) \right)}{d \omega_n} \right|_{\omega_n=0} \right] \end{aligned} \quad (7)$$

5 with $\text{Imag}[X]$ the imaginary part of the complex number X .

The derivative of $\ln(H(e^{j\omega_n}))$ equals:

$$\begin{aligned} \frac{d \left(\ln(H(e^{j\omega_n})) \right)}{d \omega_n} &= \frac{\frac{d \left(H(e^{j\omega_n}) \right)}{d \omega_n}}{H(e^{j\omega_n})} \\ &= \frac{\sum_{l=0}^{L_a-1} -j \cdot l \cdot e^{-j\omega_n l} \cdot a_{0,l}}{\sum_{l=0}^{L_a-1} e^{-j\omega_n l} \cdot a_{0,l}} \end{aligned} \quad (8)$$

10 The signal being in baseband, i.e. at the zero frequency, one seeks the group time at the centre of the useful signal, that is to say at the angular frequency $\omega_n = 0$:

$$\left. \frac{d \left(\ln(H(e^{j\omega_n})) \right)}{d \omega_n} \right|_{\omega_n=0} = \frac{\sum_{l=0}^{L_a-1} -j \cdot l \cdot a_{0,l}}{\sum_{l=0}^{L_a-1} a_{0,l}}. \quad (9)$$

Of course, when the signal is not in baseband, the ω_n considered can be adapted accordingly.

The delay Δ_t is expressed by virtue of the previous formulation in the following manner:

$$\begin{aligned}\Delta_t &= \text{Imag} \left[\frac{d \left(\ln \left(H(e^{j\omega_n}) \right) \right)}{d \omega_n} \right]_{\omega_n=0} \\ &= \text{Imag} \left[-j \cdot \frac{\sum_{l=0}^{L_a-1} l \cdot a_{0,l}}{\sum_{l=0}^{L_a-1} a_{0,l}} \right]\end{aligned}\quad (10)$$

5 Finally, the simplified expression for the delay Δ_t is:

$$\Delta_t = -\text{Real} \left[\frac{\sum_{l=0}^{L_a-1} l \cdot a_{0,l}}{\sum_{l=0}^{L_a-1} a_{0,l}} \right], \quad (11)$$

with $\text{Real}[X]$ the real part of the complex number X .

The offset Δ_t that has to be applied by the fine time-synchronization can therefore be calculated very simply on the basis of the L_a predistortion
10 coefficients $a_{0,l}$.

Equation (11) can be generalized by taking into account negative index linear coefficients, that is to say for indices $l = [-L'_a; L_a - 1]$ instead of $l = [0; L_a - 1]$.

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When the predistortion model used does not take memory effects into account, such as for example the algorithms based on a simple polynomial model such as that described in equation (12):

$$y(n) = \sum_{k=0}^{K_a-1} a_k x(n) |x(n)|^k, \quad (12)$$

it is impossible to calculate the group time on the basis of the linear
20 coefficient a_0 alone. A few linear coefficients can then be added to take into account the delay between the two signals, for example:

$$y(n) = \sum_{k=0}^{K_a-1} a_k x(n) |x(n)|^k + \sum_{l=0}^{L_a-1} a_{0,l} x(n-l). \quad (13)$$

This model, on which the invention can be implemented simply, pertains to that presented in equation (2).

Equation (11), making it possible to express the fine propagation delay
 5 on the basis of the predistortion coefficients, is applicable to all the
 predistortion models derived from the various Volterra series (SV, MP, GMP,
 DDR, etc...). However, the invention applies for all the other predistortion
 families. For example, the relation between the input and the output of the
 predistortion of DVR type (English acronym for Decomposed Vector
 10 Rotation) described in A. Zhu, "Decomposed Vector Rotation-Based
 Behavioral Modeling for Digital Predistortion of RF Power Amplifiers," in IEEE
 Transactions on Microwave Theory and Techniques, vol. 63, no. 2, pp. 737-
 744, Feb. 2015, is expressed in the following manner:

$$\begin{aligned} y(n) = & \sum_{i=0}^M a_i x(n-i) \\ & + \sum_{k=1}^K \sum_{i=0}^M c_{ki,1} |x(n-i)| - \beta_k |e^{j\theta(n-i)}| \\ & + \sum_{k=1}^K \sum_{i=0}^M c_{ki,21} |x(n-i)| - \beta_k |e^{j\theta(n-i)}| x(n) \\ & + \sum_{k=1}^K \sum_{i=1}^M c_{ki,22} |x(n-i)| - \beta_k |x(n)| \\ & + \sum_{k=1}^K \sum_{i=1}^M c_{ki,23} |x(n-i)| - \beta_k |x(n-i)| \\ & + \sum_{k=1}^K \sum_{i=1}^M c_{ki,24} |x(n)| - \beta_k |x(n-i)| \\ & + \dots \end{aligned}$$

In the same manner as for the GMP model, if one considers only the
 15 linear terms a_i of the DVR model, the expression for the delay Δ_t may be
 written:

$$\Delta_t = - \text{Real} \left[\frac{\sum_{l=0}^M l \cdot a_l}{\sum_{l=0}^M a_l} \right], \quad (14)$$

The device for transmitting a signal according to the invention therefore makes it possible to exploit the low complexity of implementation of a coarse synchronization, and then utilizes the time dimension of the calculated
 5 predistortion coefficients to refine an optimal sampling instant. It is very simple to implement and does not require any complex calculations.

Since this involves a digital predistortion algorithm, all of the processing, that is to say the analysis of the coefficients 203 and the application of the
 10 fine time-synchronization 202, is carried out by a digital calculation circuit. For example, it may be carried out by a reprogrammable calculation machine such as a processor, a DSP (English acronym for Digital Signal Processor), or a micro controller. It can also be carried out by a dedicated calculation machine, such as an FPGA (English acronym for Field-Programmable Gate
 15 Array) or an ASIC (English acronym for Application Specific Integrated Circuit), or by any other hardware module allowing the execution of calculations.

The digital calculation circuit may be embedded in an RF or wired transmission apparatus, or in any other apparatus intended to emit a
 20 modulated signal, under real conditions or in the laboratory, such as for example a signal generator or a computer.

Figures 3a and 3b are representations, given by way of illustration, of signals which are resynchronized respectively without implementing and by
 25 implementing the invention

In Figure 3a, the signal 301 to be transmitted and the signal 302 emitted and downsampled are resynchronized temporally according to the low-complexity procedures known from the prior art. The temporal compensation is comparable to the temporal compensation carried out by the coarse time-
 30 synchronization carried out by a transmission apparatus according to one embodiment of the invention. A delay, corresponding to the fractional delay

related to the differences in sampling instants between the oversampler 101 and the downsampler 113, implies that the two signals are not exactly in phase, this having consequences on the predistortion coefficients calculated and therefore on the spectral regrowths of the emitted signal.

5 Conversely, in Figure 3b, the signal to be transmitted 301 and the downsampled emitted signal 303 are resynchronized such as described in the invention. This resynchronization comprises coarse time-resynchronization, making it possible to resynchronize the signals to within a few samples, and fine resynchronization, estimated on the basis of the
10 predistortion coefficients. The two signals are then perfectly synchronized, thus making it possible to optimize the calculation of the predistortion coefficients, and therefore the shape of the spectrum emitted after amplification by an amplifier whose response is not necessarily linear.

15 The invention also pertains to a method for temporally synchronizing two signals in a signal transmission device, the two signals being used by a predistortion calculation loop to calculate predistortion coefficients applied to the signal to be transmitted before its amplification and its emission.

 According to the embodiment, the two signals can be the predistorted
20 signal and the emitted signal, taken either in the downsampled domain or in the oversampled domain. It may also entail the signal to be transmitted (that is to say before predistortion) and the emitted signal.

 Figure 3 is a representation in the form of a state chart of the steps of
25 an embodiment of the method of time synchronization according to the invention.

 This method comprises a first step 301 of applying a first, coarse, time offset 114. This first time offset corresponds substantially to the gap between the two signals to be synchronized, although, in order for its implementation
30 cost to be as low as possible, it does not seek to estimate the offset with significant precision. This offset may then be an offset calculated theoretically, measured on the basis of a calibration signal, or obtained by correlation between the two signals to be temporally synchronized, preferably

in the downsampled domain by using sequences of reasonable size. In practice, the signal to be transmitted, or the predistorted signal, will generally be stored in a memory buffer, the predistortion loop retrieving the signal from the memory buffer at a position which depends on the present instant and on
5 the calculated time offset.

It also comprises a second step 302 of applying a second, fine, time offset 202. This second time offset seeks to compensate the residual gap between the signals after application of the coarse time offset. It is calculated on the basis of the predistortion coefficients, and seeks to achieve a
10 precision of less than the duration of a sample in the downsampled domain. Advantageously, only the linear predistortion coefficients are used to calculate the value of this second offset. Advantageously, so as to reduce the complexity of implementation of the method, the second offset is applied before the downsampling 113 of the emitted signal.

15 The two steps are carried out consecutively, their order being unimportant, on all the data used by the predistortion calculation loop.

Various embodiments of the method are possible.

According to a first embodiment, the coarse synchronization is a fixed
20 value, calculated theoretically or in the factory. In this embodiment, the offset carried out by this synchronization does not vary over time.

According to a second embodiment, the coarse synchronization is calculated by virtue of a calibration signal, or by correlation of the signals to be transmitted (predistorted or not) with the digitized emitted signal. It can
25 then be calculated at precise moments, such as for example during initialization of the apparatus, or at regular intervals, or calculated on the fly continuously or by data blocks to be transmitted.

In all these embodiments, the role of the fine synchronization is to
30 correct the defects of this synchronization, and to follow the variations of the group time. It too can be carried out at specific instants, at regular intervals, or in a continuous manner throughout transmission.

When the predistortion coefficients applied to the data to be transmitted do not modify them, which may be the case when the first few data are passing through the predistortion calculation loop, the offset Δt applied by the fine synchronization is zero.

CLAIMS

1. Method for temporally synchronizing two signals in a signal transmission device, the two signals being used by a predistortion calculation
5 loop (201) to calculate predistortion coefficients (115) applied to the signal to be transmitted before its amplification (103) and its emission, the method being characterized in that it comprises consecutively:
 - the application (601) of a first time offset (114) corresponding substantially to the time gap between the two signals, and
 - 10 - the application (602) of a second time offset (202) corresponding substantially to the time gap between the two signals after application of the first time offset, the second time offset being calculated on the basis of the said predistortion coefficients.
- 15 2. Method for temporally synchronizing two signals according to Claim 1, in which the first time offset is an offset calculated theoretically, measured on the basis of a calibration signal, or obtained by correlation between the two signals to be temporally synchronized.
- 20 3. Method for temporally synchronizing two signals according to one of the preceding claims, in which the two signals to be temporally synchronized are:
 - a first signal corresponding to the signal to be transmitted before or after application of the predistortion,
 - 25 - a second signal corresponding to the emitted signal.
4. Method for temporally synchronizing two signals according to one of the preceding claims, in which the second time offset is calculated on the basis of the predistortion coefficients which are expressed linearly as a
30 function of the signal to be transmitted.

5. Method for temporally synchronizing two signals according to Claim 4, in which the second time offset Δt equals:

$$\Delta t = -\text{Real} \left[\frac{\sum_{l=0}^{L_a-1} l \cdot a_{0,l}}{\sum_{l=0}^{L_a-1} a_{0,l}} \right],$$

where $a_{0,l}$ represents L_a predistortion coefficients expressed linearly as a function of the signal to be transmitted, and $\text{Real}(X)$ the real part of the complex number X .

6. Method for temporally synchronizing two signals according to Claim 4, in which the second time offset Δt equals:

$$\Delta t = -\text{Real} \left[\frac{\sum_{l=0}^M l \cdot a_l}{\sum_{l=0}^M a_l} \right],$$

where a_l represents M predistortion coefficients expressed linearly as a function of the signal to be transmitted, and $\text{Real}(X)$ the real part of the complex number X .

7. Method for temporally synchronizing two signals according to one of the preceding claims, in which the processings carried out by the predistortion calculation loop comprise the downsampling of the signal emitted, and where the second time offset is applied before the said downsampling.

8. Device for transmitting a signal comprising a predistortion calculation loop (201) for calculating predistortion coefficients applied to the signal to be transmitted, and an amplifier (103) for amplifying and emitting the said predistorted signal, characterized in that it comprises:

- an application means (114) for applying a first time offset of two signals used by the predistortion calculation loop, configured to substantially compensate the time gap between the two signals, and
- an application means (202) for applying a second time offset of the two signals used by the predistortion calculation loop, configured to

substantially compensate the time gap between the two signals after application of the first time offset, the second time offset being calculated on the basis of the said predistortion coefficients.