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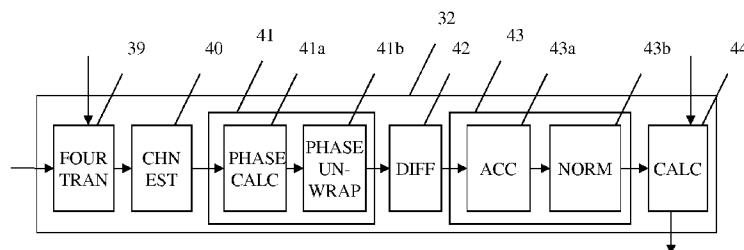
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(54) **Title:** MEASURING DEVICE AND MEASURING METHOD FOR HIGH RESOLUTION TIME SYNCHRONIZATION IN OFDM SYSTEMS



**Fig. 6**

(57) **Abstract:** A measuring device for measuring a symbol start time in a first signal of a device under test comprises reception means for receiving the first signal and processing means for processing the first signal. The processing means comprise synchronization calculation means (32) for calculating the symbol start time comprising channel estimation means (40) for estimating channel response parameters, phase means (41) for calculating phase values from the channel response parameters, differentiating means (42) for performing a differentiation of the phase values, and calculation means (44) for calculating the symbol start time from the differentiated phase values.

**Measuring device and measuring method for high resolution  
time synchronization in OFDM systems**

The invention relates to a measuring device and a  
5 measuring method for accurately measuring a symbol start  
time in a signal of a device under test.

In regular OFDM receivers, time synchronization is usually  
performed by means of correlation of known pilot symbols  
10 and received pilot symbols. This method though requires a  
great deal of computing power and is limited by principle  
on an accuracy of no more than the distance between two  
sample points.

15 For example, the international patent application WO  
2008/116534 A1 shows a method and system for determining a  
channel impulse response in an OFDM transmission system  
including determining the timing of the OFDM symbols with  
the system and method shown there only a relative low  
20 synchronization accuracy can be reached.

Accordingly, the object of the present invention is to  
create a measuring device and measuring method for  
accurately measuring a symbol start time in a signal of a  
25 device under test.

The object is solved by the features of claim 1 for the  
measuring device and by the features of claim 9 for the  
measuring method. The dependent claims contain further  
30 developments.

An inventive measuring device for measuring a symbol start  
time in a first signal of a device under test comprises  
reception means for receiving the first signal, and

processing means for processing the first signal. The  
processing means further comprise synchronization  
calculation means for calculating the symbol start time  
comprising channel estimation means for estimating channel  
5 response parameters, phase means for calculating phase  
values from the channel response parameters,  
differentiating means for performing a differentiation of  
the phase values, and calculation means for calculating  
the symbol start time from the differentiated phase  
10 values. It is therefore possible to accurately calculate  
the actual start time.

The processing means advantageously comprise  
synchronization estimation means for determining an  
15 estimated symbol start time. The calculation means are  
then set up for calculating the symbol start time by  
adding a value derived from the differentiated phase  
values to the estimated symbol start time. By use of this  
two-step approach, a reduced computational complexity can  
20 be reached.

Advantageously, the phase means comprise phase calculation  
means for calculating phase values from the channel  
response parameters and phase unwrapping means for  
25 performing a phase unwrapping of the phase values. This  
allows a simple and accurate calculation of the phase  
values.

The processing means advantageously further comprise  
30 averaging means for calculating a weighted average of the  
differentiated phase values. The calculation means are  
then set up for calculating the symbol start time by  
adding the weighted average to the estimated symbol start  
time. This allows an increase in accuracy.

Advantageously, the averaging means comprise accumulation means for performing an accumulation of at least two differentiated phase values and normalization means for  
5 determining the weighted average by performing a normalization of the accumulated differentiated phase values. A simple averaging is therefore reached.

The normalization means are advantageously set up for  
10 normalizing the accumulated differentiated phase values with a preset parameter. This allows an easy calculation of the start time.

Advantageously, the channel estimation means estimate the  
15 channel response parameters by using received pilot symbols within the first signal and known pilot symbols defined by an employed communication standard. An easy channel estimation is thereby reached.

20 An inventive measuring method serves the purpose of measuring a symbol start time in a first signal of a device under test. The method comprises receiving the first signal and processing it. Moreover the method comprises calculating the symbol start time by estimating  
25 channel response parameters, calculating phase values from the channel response parameters, performing a differentiation of the phase values, and calculating the symbol start time from the differentiated phase values. It is therefore possible to accurately calculate the actual  
30 start time.

An exemplary embodiment of the invention is now further explained with respect to the drawings as a non-limiting example only, in which

- Fig. 1 shows several OFDM symbols in a first time diagram;
- 5 Fig. 2 shows several OFDM symbols in a second time diagram;
- Fig. 3 shows an OFDM symbol and a number of relevant parameters in a time diagram;
- 10 Fig. 4 shows an embodiment of the inventive measuring device in a block diagram;
- Fig. 5 shows a first detail of the embodiment of the inventive measuring device in a block diagram;
- 15 Fig. 6 shows a second detail of the embodiment of the inventive measuring device in a block diagram, and
- 20 Fig. 7 shows an embodiment of the inventive measuring method.

First, we demonstrate along Fig. 1-3 the underlying  
25 problem and the general principle of the present invention. Along Fig. 4-6, the construction and function of an embodiment of the inventive measuring device are shown. Finally, along Fig. 7, the function of an embodiment of the inventive measuring method is shown.

30

Similar entities and reference numbers in different figures have been partially omitted.

The present invention is set up for working with communication standards using known pilot symbols, as for example OFDM. From an output of an OFDM modulator at a transmitter to the input of an OFDM demodulator at a receiver, we are dealing with I/Q samples in the time-domain while we are dealing with I/Q samples in the frequency-domain at other processing stages.

The relationship between I/Q samples in time-domain  $x(n)$  and I/Q samples in frequency-domain  $X(k)$  is given through the Discrete Fourier Transform (DFT):

$$X(k) = \sum_{n=0}^{N_{DFT}-1} x(n) * \exp(-j * 2 * \pi * k * n / N_{DFT})$$

with

$$N_{DFT} = \frac{T_{symp}}{T_s} = N_{symp}$$

where  $T_{symp}$  is the OFDM symbol length [sec],  $N_{symp}$  is the OFDM symbol number [number of samples] and  $T_s = 1/f_s$ , where  $f_s$  is the sampling frequency [Hz].

An exemplary synchronization approach in OFDM systems is the continuous evaluation of an appropriate correlation function  $m(t)$ . Here one exploits that the end of each OFDM symbol is repeated at its beginning as Cyclic Prefix (CP) before transmission. A possible correlation function could be

$$m(n) = \frac{\sum_{l=0}^{N_w-1} x(n-l) * x^*(n-l-N_{\text{sybm}})}{\frac{1}{2} \sum_{l=0}^{N_w-1} (|x|^2(n-l) + |x|^2(n-l-N_{\text{sybm}}))}$$

where  $x(n)$ ,  $N_{\text{sybm}}$  and  $N_w$  denote the sampled OFDM signal,  
the OFDM symbol length [number of samples] and correlation  
5 window length [number of samples] respectively.

In Fig. 1, this correlation function 16a is plotted versus  
an ideal OFDM signal for  $N_w = N_{\text{CP}}$ , where  $N_{\text{CP}}$  is the cyclic  
prefix length [number of samples]. Fig. 1 shows two OFDM  
10 symbols 11a, 11b, each including an end portion 12a, 12b  
which is used as the cyclic prefix 10a, 10b at the  
beginning of the respective OFDM symbol 11a, 11b. One can  
observe that there are distinct correlation peaks 17a,  
18a, 19a of a correlation function 16a at the symbol  
15 boundaries that allow for accurate synchronization.

However, there are cases where the transmitter weights the  
OFDM signal after cyclic prefix (CP) insertion with a  
window function before transmission. If the receiver now  
20 chooses the correlation window length  $N_w = N_{\text{CP}}$  this leads  
to a severe degradation of the correlation peak. Thus, a  
robust thresholding for correlation peak detection is not  
possible. In order to circumvent this problem, the  
correlation window length has to be reduced  $N_w < N_{\text{CP}}$ . Thus,  
25 in turn one loses the distinct correlation peak and  
obtains a correlation plateau instead. This can easily be  
seen from Fig. 2, in which the changed correlation  
function 16b and the correlation plateaus 17b, 18b and 19b  
are shown. Moreover the windowing function 9 is shown in  
30 Fig. 2.. The timing estimation accuracy is limited by the  
plateau length  $N_{\text{CP}} - N_w$  and we have  $|T_{\text{syncerror}}| < N_{\text{CP}} - N_w$ , where

$T_{\text{syncerror}}$  is the synchronization error. Even if we assume that there are no channel effects and no Additional White Gaussian Noise (AWGN) the inequality  $|T_{\text{syncerror}}| < N_{\text{CP}} - N_{\text{W}}$  cannot be tightened.

5

In order to increase synchronization accuracy, a timing estimation technique is proposed, which is efficient, i.e.  $|T_{\text{syncerror}}| \rightarrow 0$  for  $\text{SNR} \rightarrow \infty$  if we imply certain restrictions on the channel.

10

In case of a channel with a non-frequency selective phase, the digital baseband model of the channel is given as

$$H(k) = \sum_{n=0}^{N_{\text{DFT}}-1} h(n) * \exp(-j * 2 * \pi * k * n / N_{\text{DFT}}) = a(k) * \exp(j * \varphi) \quad \text{for}$$

$$15 \quad k \in \{0, \dots, N_{\text{DFT}} - 1\} \quad (1)$$

where  $a(k)$  and  $\varphi$  are real numbers. This is possible, if the transmission channel between a transmitter and a receiver produces no phase drift over frequency. This is  
 20 for example achieved in laboratory setups with a short over-the-air channel or a cable channel.

In Fig. 3 an OFDM symbol 11 is shown. The OFDM symbol 11 comprises an end part 12, which is used as cyclic prefix  
 25 10 before the OFDM symbol. The OFDM symbol 11 has the length  $T_{\text{symb}}$ . The cyclic prefix 10 and the end part 12 of the OFDM symbol 11 each have the length  $T_{\text{CP}}$ .

Moreover, in Fig. 3 an ideal receiver window 13 is shown.  
 30 This indicates the ideal time interval, in which a receiver attempts to receive the OFDM symbol 11. In this case, the receiver starts receiving the OFDM symbol 11 earlier by a duration  $T_{\text{readoffset}}$  than the actual start time

$t_{\text{ref}}$  of the OFDM symbol 11 to account for an inaccurate synchronization.  $T_{\text{readoffset}}$  is usually picked as one half of the duration  $T_{\text{CP}}$  of the cyclic prefix 10. In reality though, a synchronization error  $T_{\text{syncerror}}$  occurs. This error  
5 changes the start time  $t_{\text{sync}}$  used by the receiver for the actual receiver window 14.

Fig. 4 shows an embodiment of the inventive measuring device 1. The inventive measuring device 1 comprises  
10 reception means 20, which comprise for example an antenna and a preamplifier. Moreover, the measuring device 1 comprises analog processing means 21, connected to an analog-digital-converter 22. Connected to the analog-digital-converter 22, the measuring device 1 comprises a  
15 digital processing means 23, which in turn is connected to displaying means 24. The analog processing means 21, the digital processing means 23 and the display means 24 are connected to furthermore comprised control means 25.

20 The measuring device 1 is connected to a device under test 2, in this example a mobile telephone. The device under test 2 is connected to the reception means 20. In this example, the connection is performed using a cable. Alternatively, an over-the-air connection is possible. The  
25 reception means 20 receives a signal, for example an OFDM signal from the device under test 2 and processes it. For example, a pre-amplification is performed. The resulting signal is passed on to the analog processing means 21, which perform further analog processing. For example, a  
30 filtering and a frequency reduction to the baseband or to an intermediate frequency are performed. A resulting analog signal is passed on to the analog-digital-converter 22, which converts it to a digital signal. This digital signal is passed on to the digital processing means 23,

which performs further digital processing. For example, a synchronization, a demodulation and a decoding is performed. As part of the digital processing means 23, the measuring of the symbol start time is performed.

5

Regarding the detailed function of the digital processing means 23, it is referred to Fig. 5 and Fig. 6. Results of the digital processing means 23 are passed on to the display means 24 and displayed. The function of the analog  
10 processing means 21, the digital processing means 23 and the display means 24 are controlled by the control means 25.

In Fig. 5, a detail of the embodiment of Fig. 4 is shown.  
15 Here only the digital processing means 23 are depicted. The signal of the analog-digital-converter 22 of Fig. 4 is passed on to synchronization estimation means 30, which estimates  $t_{\text{ref}}$ , for example by the use of the before mentioned correlation. The estimate can be written as:

20

$$\hat{t}_{\text{ref}} = t_{\text{ref}} + T_{\text{syncerror}}$$

where  $T_{\text{syncerror}}$  is the synchronization error. The signal and the synchronization estimation are passed on to processing  
25 means 31, which perform further digital processing, for example a demodulation and a decoding. The function of the processing means 31 though is of no concern to the present invention. Moreover, the digital processing means comprise synchronization calculation means 32, which are also  
30 supplied with the digital signal of the analog-digital-converter 22 of Fig. 4. Moreover, the synchronization calculation means 32 are provided with the synchronization estimation of the synchronization estimation means 30. The synchronization calculation means 32 calculate a precise

symbol start time in the signal of the device under test 2  
of Fig. 4 and pass on the exact synchronization  
information to the processing means 31. Regarding the  
function of the synchronization calculation means 32, it  
5 is referred to Fig. 6.

Fig. 6 shows a further detail of the embodiment of the  
inventive measuring device 1 of Fig. 4. Here the  
synchronization calculation means 32 of Fig. 5, which are  
10 comprised by the digital processing means 23 of Fig. 4,  
are shown in detail. The synchronization calculation means  
32 comprise fourier transformation means 39, channel  
estimation means 40, which are connected to phase means  
41. The phase means 41 comprise phase calculation means  
15 41a, which are connected to the channel estimation means  
40 and phase unwrapping means 41b which are connected to  
the phase calculation means 41a. Moreover, the  
synchronization calculation means 32 comprise  
differentiation means 42, which are connected to the phase  
20 unwrapping means 41b of the phase means 41. Moreover, the  
differentiation means 42 are connected to averaging means  
43. The averaging means 43 comprise accumulation means  
43a, which are connected to the differentiation means 42,  
and normalization means 43b, which are connected to the  
25 accumulation means 43a. Moreover, the synchronization  
calculation means 32 comprise calculation means 44, which  
are connected to the normalization means 43b of the  
averaging means 43.

30 The time offset

$$T_{\text{offset}} = T_{\text{readoffset}} + T_{\text{syncerror}}$$

is calculated as shown in the following. The fourier transformation means 39 are provided with the digitized signal of the analog-digital-converter 22 of Fig. 4. The fourier transformation means 39 perform a fourier transformation, advantageously a fast fourier transformation, in order to transform the signal into the frequency domain. The channel estimation means are provided with the signal in the frequency domain and with the synchronization estimation of the synchronization estimation means 30 of Fig. 5. The channel estimation means 40 perform a channel estimation based on known pilot symbols and based on received pilot symbols within the digital signal. The pilot symbols are known from the employed communication standard. The channel estimation means 40 produces channel response parameters as a result. As described earlier, the channel response parameters comprise information, which can be used to calculate an exact synchronization. The channel estimation means 40 estimate the channel

20

$$\hat{H}(k), k \in \{k_0, k_0 + 1, \dots, k_0 + L - 1\}$$

for L pilot subcarriers. For the sake of brevity, we assume here that the L pilots are distributed continuously over the subcarriers k. However, our proposed approach can easily be adapted to other distributions.

In an alternative embodiment, the synchronization calculation means 32 do not comprise the fourier transformation means 39 and the channel estimation means 40. In this case, the fourier transformation means 39 and the channel estimation means 40 are located within the processing means 31. In this case, the synchronization calculation means 32 receives an input signal for the

phase means 41 from the processing means 31. This embodiment is advantageous, since for decoding an OFDM signal, a channel estimation and a fourier transformation are needed anyway. In this alternative embodiment  
 5 calculation complexity can therefore be reduced.

By making use of the circular shift property of the DFT

$$X \left[ (n - m)_{N_{DFT}} \right] \leftrightarrow \exp \left( -j * 2 * \pi * \frac{k}{N_{DFT}} * m \right) * X[k]$$

10

where  $(.)_{N_{DFT}}$  denotes the modulo  $N_{DFT}$  operator and we assume that  $x[n] \leftrightarrow X[k]$ , and according to the equation (1) the output  $\hat{H}(k)$  of the channel estimator can be modeled as

$$15 \quad \hat{H}(k) = a(k) * \exp \left( j * \left( -2 * \pi * \frac{k}{N_{DFT}} * N_{offset} + \varphi \right) \right) + n(k) \quad \text{for}$$

$$k \in \{k_0, k_0 + 1, \dots, k_0 + L - 1\}$$

where  $N_{offset} = N_{syncerror} + N_{readoffset}$  and  $N_{syncerror}$  and  $N_{readoffset}$  are the synchronization error and the readoffset in  
 20 multiples of  $T_s$  [number of samples] respectively, and  $n(k)$  is White Gaussian Noise (WGN).

The channel response parameters are transmitted to the phase means 41, more precisely to the phase calculation  
 25 means 41a. The phase calculation means 41a determine phase values.

$$y(k) = -2 * \pi * \frac{k}{N_{DFT}} * N_{offset} + \varphi + n'(k) .$$

These phase values contain the synchronization error as described earlier. These phase values are passed on to the phase unwrapping means 41b, which perform a phase unwrapping. This means that a continuous phase is  
 5 calculated from the phase values, which can comprise phase jumps. The resulting unwrapped phase values are passed on to the differentiation means 42, which calculate differentiated unwrapped phase values.

$$10 \quad y'(k) = -2 * \pi * \frac{N_{offset}}{N_{DFT}} + n''(k)$$

for  $k \in \{k_0 + 1, \dots, k_0 + L - 1\}$

In an alternative embodiment, the phase means 41 do not  
 15 comprise phase unwrapping means 41b. In this case, the phase calculation means 41a are directly connected to the differentiation means 42. The differentiation means 42 are then connected to unwrapping means set up for removing the discontinuities that are removed by the phase unwrapping  
 20 means 41b in the above described setup. These unwrapping means are then connected to the averaging means 43.

The differentiated unwrapped phase values are then passed on to the averaging means 43, which perform a weighted  
 25 average of the differentiated unwrapped phase values. This is done by handing the differentiated unwrapped phase values to the accumulation means 43a, which accumulate at least two successive differentiated unwrapped phase values. A large number of differentiated unwrapped phase  
 30 values can be accumulated by the accumulation means 43a.

$$y'_{accumulated} = -2 * \pi * \frac{N_{offset}}{N_{DFT}} * (L - 1) + \sum_{k=k_0+1}^{k_0+L-1} n''(k)$$

After finishing the accumulation 43a, the resulting sum of the differentiated unwrapped phase values is passed on to the normalization means 43b, which performs a  
 5 normalization using a predefined parameter, thus from  $y'_{\text{accumulated}}$  we obtain an estimate

$$\hat{N}_{\text{offset}} = -\frac{y'_{\text{accumulated}} * N_{\text{DFT}}}{2 * \pi * (L-1)}$$

10  $\hat{T}_{\text{offset}} = \hat{N}_{\text{offset}} * T_s$

The preset parameter used for normalization is configurable and therefore can be changed during operation of the measuring method and measuring device.

15

The resulting value  $\hat{T}_{\text{offset}}$  now corresponds to  $\hat{T}_{\text{syncerror}} + T_{\text{readoffset}}$ .

It is passed on to the calculation means 44, which calculates the symbol start  $t_{\text{ref}}$  time adding the weighted average  $\hat{T}_{\text{offset}}$  to the estimated symbol start time  $t_{\text{sync}}$

20 provided by the synchronization estimation means 30 of Fig. 5.

Finally we have:

25  $\hat{t}_{\text{ref}} = t_{\text{sync}} + \hat{T}_{\text{offset}}$

Alternatively, the averaging means 43 can be omitted. In this case, the differentiated unwrapped phase values resulting from the differentiation means 42 are directly  
 30 passed on to the calculation means 44. In this case though, the calculation means 44 has to perform a normalization of the resulting value of the

differentiation means 42 before calculating the symbol start time.

In Fig. 7, an exemplary embodiment of the inventive measuring method is shown. In a first step 100, a synchronization estimation is performed. A correlation of known pilot symbols with received pilot symbols can be used. The result is an estimated symbol start time  $t_{\text{sync}}$ . Either as part of performing the synchronization estimation or independent of it, moreover this step includes performing a fourier transformation of the signal into the frequency domain. In a second step 101, a channel estimation is performed. For example, known pilot symbols and the received pilot symbols are used. Resulting channel response parameters are used in a third step 102 to calculate phase values. These are subjected to a phase unwrapping in a fourth step 103. The unwrapped phase values are differentiated in a fifth step 104. The resulting differentiated unwrapped phase values are accumulated in a sixth step 105. In this step, a predefined number of unwrapped phase values is added. In a seventh step 106, a normalization of the accumulated differentiated unwrapped phase values is performed. This normalization is performed using a predefined normalization parameter. In an eighth step 107, the resulting value from the seventh step 106 is added to the synchronization estimation value resulting in the symbol start time.

The invention is not limited to the examples and especially not to any OFDM communication standard. Many different communication standards can be used. The characteristics of the exemplary embodiments can be used in any advantageous combination of the features claimed in

the claims and/or described in the description and/or drawn in the drawings.

**Claims**

1. Measuring device for measuring a symbol start time ( $t_{\text{ref}}$ ) in a first signal of a device under test,  
5 comprising:  
- reception means (20) for receiving the first signal, and  
- processing means (21, 22, 23, 25) for processing the first signal,  
**characterized in that**  
10 the processing means (21, 22, 23, 25) comprise synchronization calculation means (32) for calculating the symbol start time ( $t_{\text{ref}}$ ) comprising:  
- channel estimation means (40) for estimating channel response parameters,  
15 - phase means (41) for calculating phase values from the channel response parameters,  
- differentiating means (42) for performing a differentiation of the phase values, and  
- calculation means (44) for calculating the symbol start  
20 time ( $t_{\text{ref}}$ ) from the differentiated phase values.
2. Measuring device according to claim 1,  
**characterized in that**  
the processing means (21, 22, 23, 25) comprise  
25 synchronization estimation means (30) for determining an estimated symbol start time ( $t_{\text{sync}}$ ), and  
the calculation means (44) are set up for calculating the symbol start time ( $t_{\text{ref}}$ ) by adding a value derived from the differentiated phase values to the estimated symbol start  
30 time ( $t_{\text{sync}}$ ).
3. Measuring device according to claim 1 or 2,  
**characterized in that**  
that the phase means (41) comprise:

- phase calculation means (41a) for calculating phase values from the channel response parameters, and
- phase unwrapping means (41b) for performing a phase unwrapping of the phase values.

5

4. Measuring device according to any of the claims 1 to 3,  
**characterized in that**

the processing means (21, 22, 23, 25) further comprise averaging means (43) for calculating a weighted average of  
10 the differentiated phase values, and  
the calculation means (44) are set up for calculating the symbol start time ( $t_{\text{ref}}$ ) by adding the weighted average to the estimated symbol start time ( $t_{\text{sync}}$ ).

15 5. Measuring device according to claim 4,

**characterized in that**

the averaging means (43) comprise:

- accumulation means (43a) for performing an accumulation of at least two differentiated phase values, and
- 20 - normalization means (43b) for determining the weighted average by performing a normalization of the accumulated differentiated phase values.

6. Measuring device according to claim 5,

25 **characterized in that**

the normalization means (43b) are set up for normalizing the accumulated differentiated phase values with a configurable preset parameter.

30 7. Measuring device according to any of the claims 1 to 6,  
**characterized in that**

the channel estimation means (40) are set up for estimating the channel response parameters by using received pilot symbols within the first signal and known

pilot symbols, defined by an employed communication standard.

8. Measuring device according to any of the claims 1 to 7,

5 **characterized in that**

the first signal is an OFDM signal using a cyclic prefix for each symbol.

9. Measuring method for measuring a symbol start time

10 ( $t_{\text{ref}}$ ) in a first signal of a device under test, comprising the following steps:

- receiving the first signal, and
- processing the first signal,

**characterized in that**

15 the method comprises calculating the symbol start time ( $t_{\text{ref}}$ ) with the following steps:

- estimating channel response parameters,
- calculating phase values from the channel response parameters,
- 20 - performing a differentiation of the phase values, and
- calculating the symbol start time ( $t_{\text{ref}}$ ) from the differentiated phase values.

10. Measuring method according to claim 9,

25 **characterized in that**

the method further comprises:

- determining an estimated symbol start time ( $t_{\text{sync}}$ ), and
- calculating the symbol start time ( $t_{\text{ref}}$ ) by adding a value derived from the differentiated phase values to the
- 30 estimated symbol start time ( $t_{\text{sync}}$ ).

11. Measuring method according to claim 9 or 10,

**characterized in that**

the method further comprises:

- calculating phase values from the channel response parameters, and
- performing a phase unwrapping of the phase values.

5 12. Measuring method according to claim 11,  
**characterized in that**

the method further comprises:

- calculating a weighted average of the differentiated unwrapped phase values, and
- 10 - calculating the symbol start time ( $t_{\text{ref}}$ ) by adding the weighted average to the estimated symbol start time ( $t_{\text{sync}}$ ).

13. Measuring method according to claim 12,  
15 **characterized in that**

the step of calculating the weighted average comprises:

- performing an accumulation of at least two differentiated phase values, and
  - determining the weighted average by performing a
- 20 normalization of the accumulated differentiated phase values.

14. Measuring method according to claim 13,  
**characterized in that**

25 the step of performing a normalization comprises normalizing the accumulated differentiated phase values with a configurable preset parameter.

15. Measuring method according to any of the claims 9 to  
30 14,  
**characterized in that**

the step of channel estimation comprises estimating channel response parameters by using received pilot

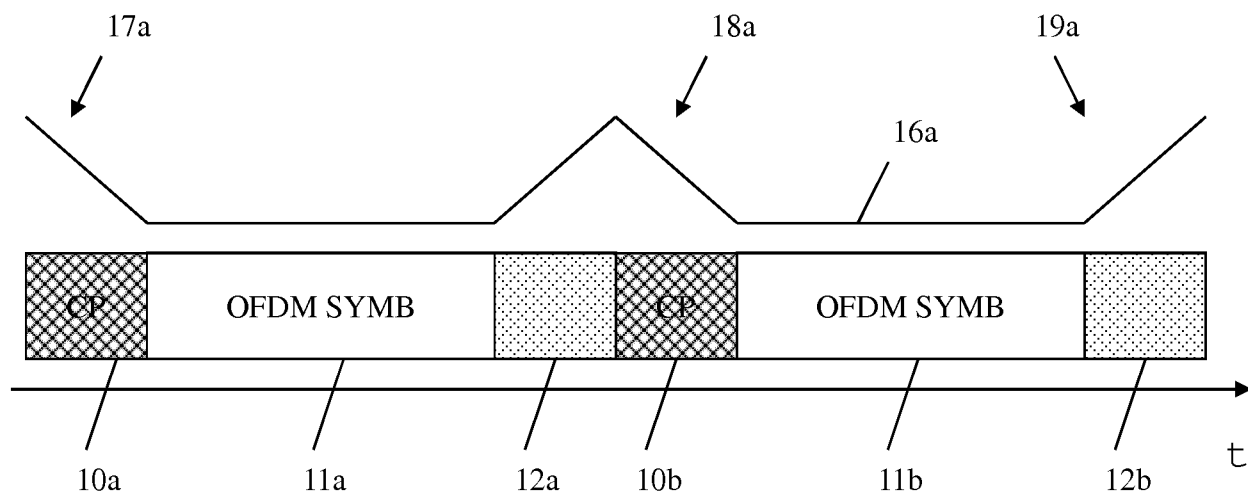
symbols within the first signal and known pilot symbols,  
defined by an employed communication standard.

16. Measuring method according to any of the claims 9 to  
5 15,

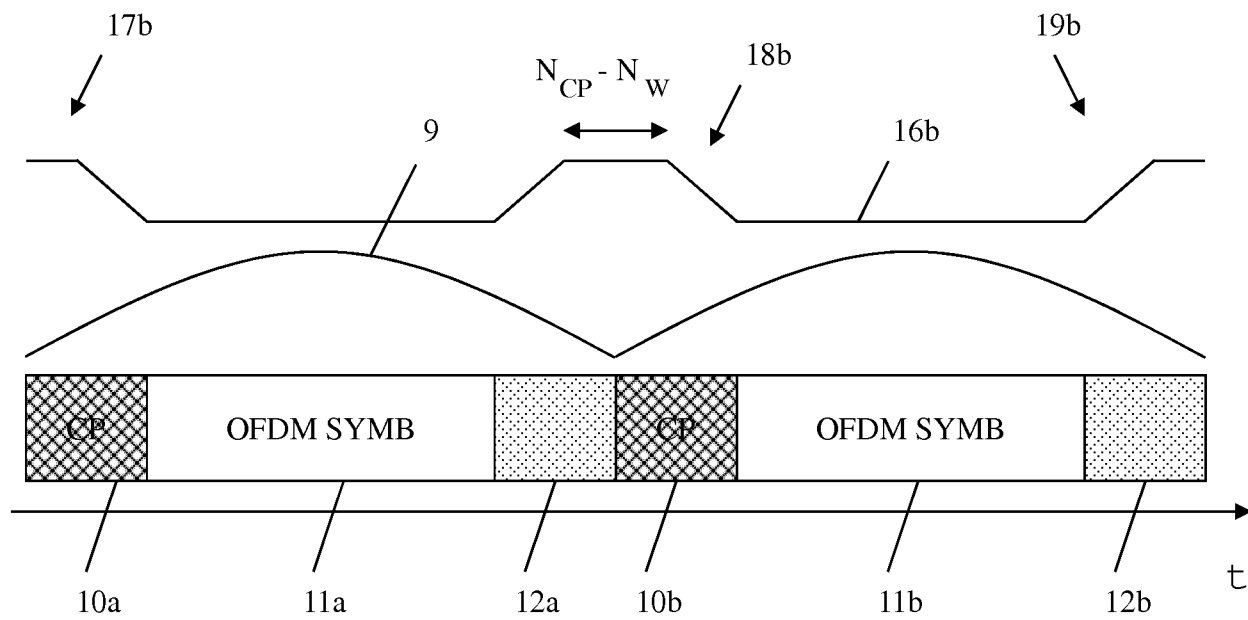
**characterized in that**

the first signal is an OFDM signal using a cyclic prefix  
for each symbol.

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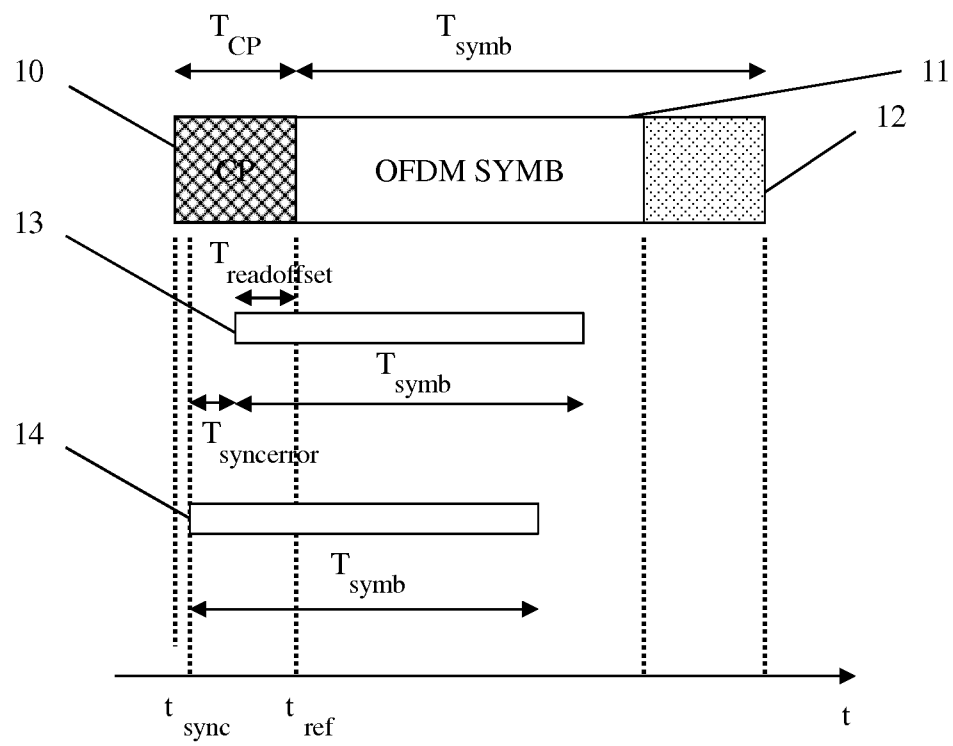


**Fig. 1**

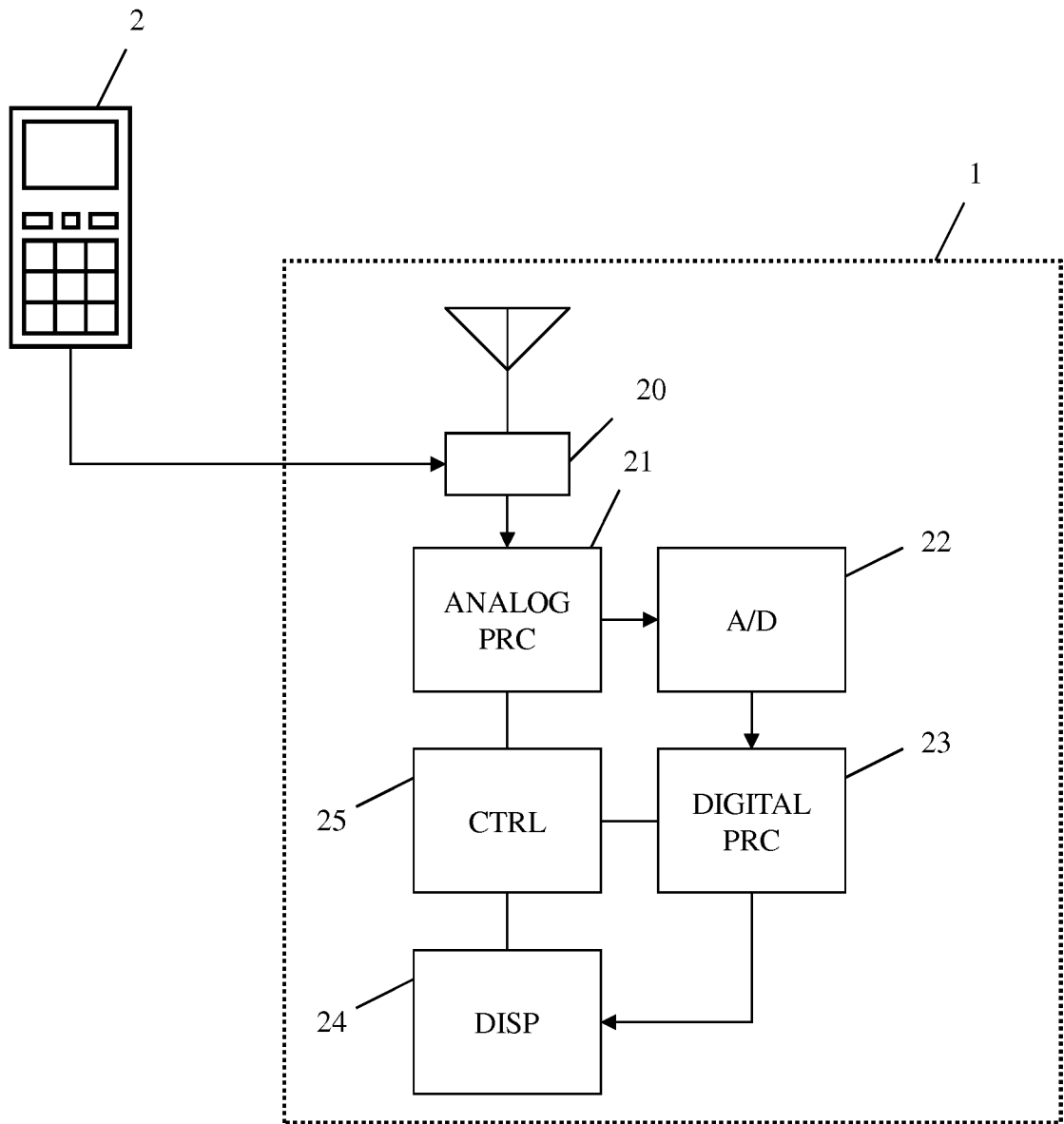


**Fig. 2**

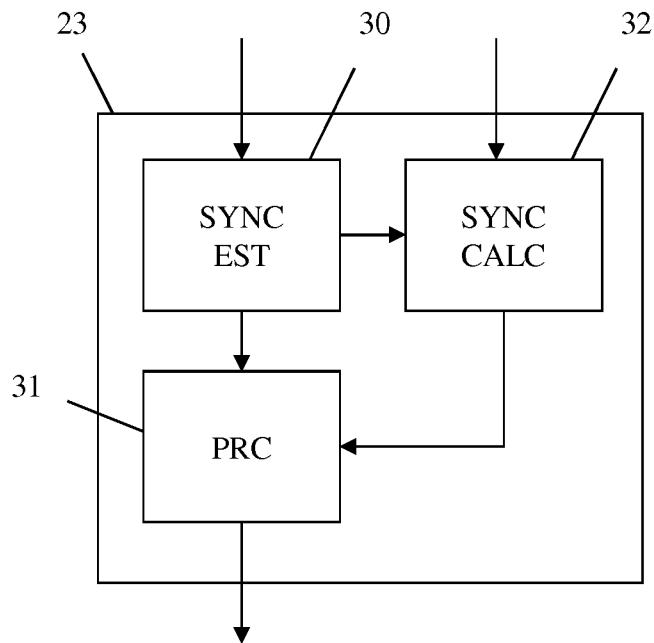
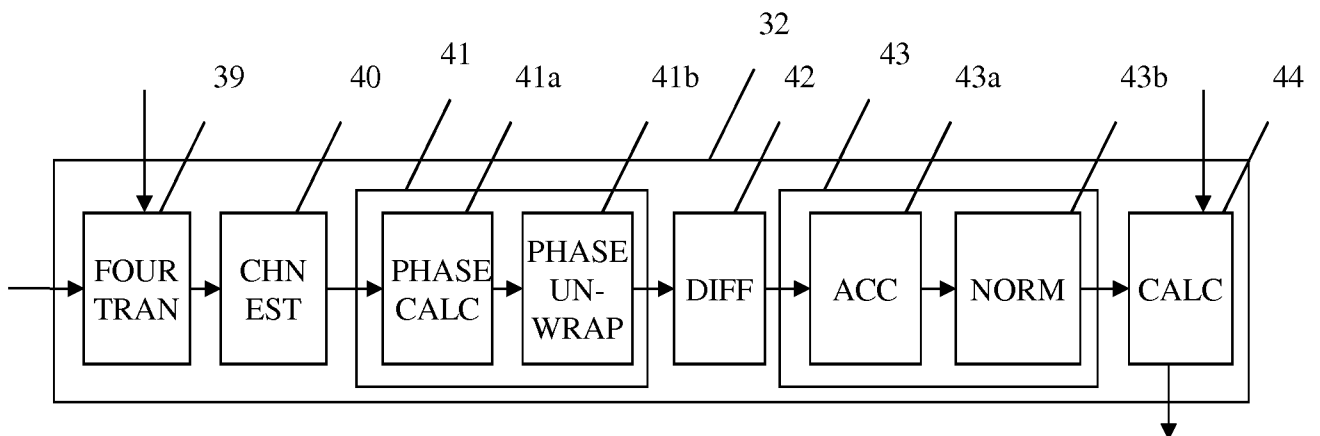
2/5

**Fig. 3**

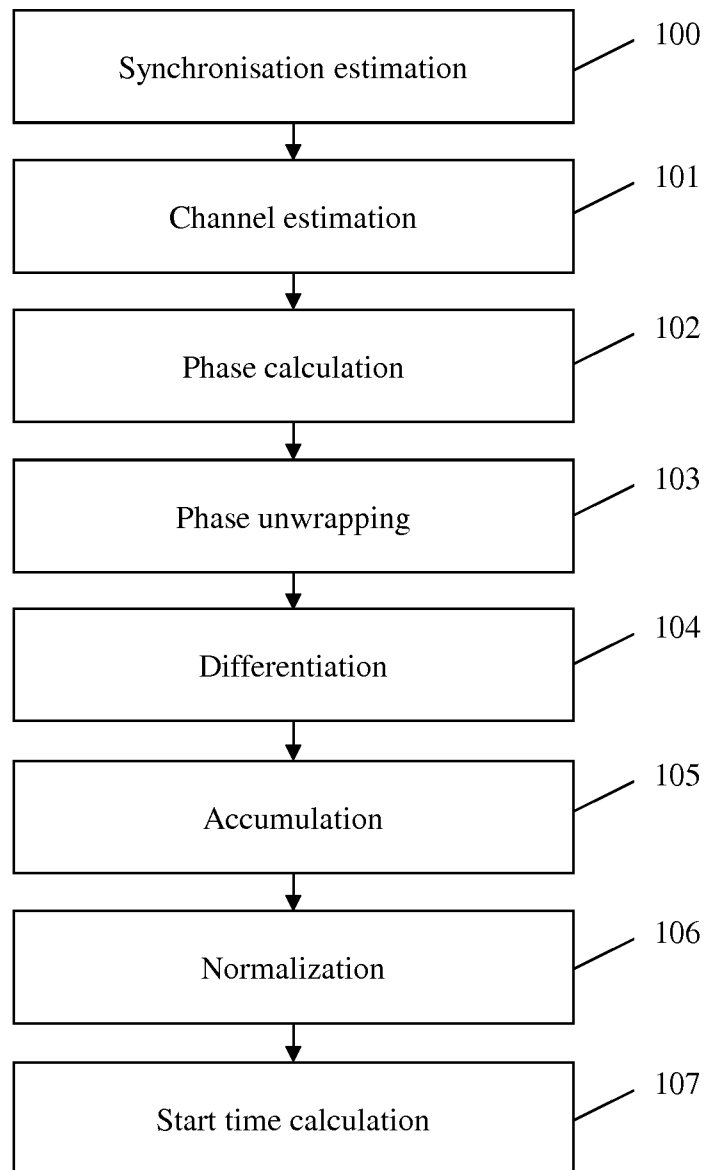
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**Fig. 4**

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**Fig. 5****Fig. 6**

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**Fig. 7**

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2013/054872

A. CLASSIFICATION OF SUBJECT MATTER  
INV. H04L27/26  
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

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 practicable, search terms used)

EPO-Internal, 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         | HAMID REZA TANHAEI ET AL: "A novel channel estimation technique for OFDM systems with robustness against timing offset",<br>IEEE TRANSACTIONS ON CONSUMER ELECTRONICS,<br>IEEE SERVICE CENTER, NEW YORK, NY, US,<br>vol. 57, no. 2, 1 May 2011 (2011-05-01),<br>pages 348-356, XP011335658,<br>ISSN: 0098-3063, DOI:<br>10.1109/TCE.2011.5955166<br>page 350 | 1-16                  |
| X         | US 2003/026371 A1 (LAROIA RAJIV [US] ET AL) 6 February 2003 (2003-02-06)<br>sentences 7-10, paragraph 12<br>paragraphs [0013] - [0015], [0017]<br>figures 3, 5<br>-----<br>-/-                                                                                                                                                                               | 1-16                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents :

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search

25 November 2013

Date of mailing of the international search report

29/11/2013

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## INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2013/054872

| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                       |
|------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Category*                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                                                                                                                                                                                                           | Relevant to claim No. |
| X                                                    | <p>DAH-CHUNG CHANG: "Effect and Compensation of Symbol Timing Offset in OFDM Systems With Channel Interpolation", IEEE TRANSACTIONS ON BROADCASTING, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 54, no. 4, 1 December 2008 (2008-12-01), pages 761-770, XP011343452, ISSN: 0018-9316, DOI: 10.1109/TBC.2008.2002339 abstract<br/>page 762, right-hand column<br/>figure 2<br/>page 763, left-hand column, lines 1-4<br/>page 764 - page 765<br/>-----</p> | 1-16                  |

## INTERNATIONAL SEARCH REPORT

### Information on patent family members

International application No

PCT/EP2013/054872

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
|-------------------------------------------|---------------------|----------------------------|---------------------|
| US 2003026371                             | A1                  | 06-02-2003                 | NONE                |
| -----                                     |                     |                            |                     |