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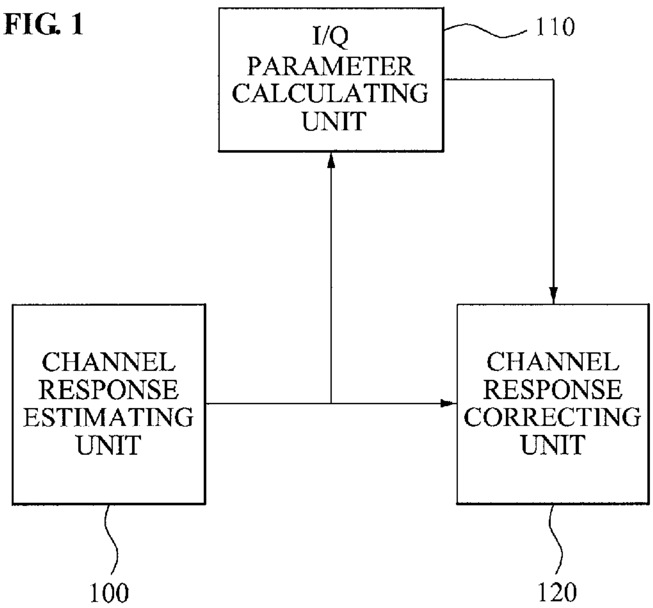
FIG. 1



(57) Abstract: Disclosed is an apparatus for receiving an Orthogonal Frequency Division Multiplexing (OFDM) signal. The apparatus includes a channel response estimating unit for receiving a frequency domain signal to estimate a channel response, an In-phase/Quadrature (IfQ) parameter calculating unit for calculating an I/Q parameter of the channel response based on a timing synchronization error of the channel response, and a channel response correcting unit for correcting the channel response using the I/Q parameter.

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METHOD OF RECEIVING ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SIGNAL AND ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SIGNAL RECEIVING DEVICE OF ENABLING THE METHOD

Technical Field

The present invention relates to an apparatus and method for receiving an Orthogonal Frequency Division Multiplexing (OFDM) signal, and more particularly, to an apparatus and method for receiving an OFDM signal that calculates an In-phase/Quadrature (I/Q) parameter to thereby correct a channel response.

Background Art

Currently, a number of users using a radio Internet are increasing dramatically. However, current radio Internet services do not provide a superior data rate and thus Internet services requiring high-speed data transmission such as multimedia services are not provided. At the same time, current users and service providers have a strong demand for technologies supporting Internet services with a reasonable price which are used regardless of time, place, and the like.

In this regard, various kinds of signal transmission schemes have been suggested. As an example of these, an Orthogonal Frequency Division Multiplexing (OFDM) scheme is representative. The OFDM scheme effectively uses a relatively broadened frequency band. A lso, the OFDM scheme transmits in parallel a plurality of carriers being orthogonal, and thus a frequency selective fading generated when data is transmitted at a high speed in a relatively broadened frequency band may be overcome.

Most communication systems using a phase or frequency modulation scheme divide signals into an In-phase (I) channel and a Quadrature (Q) channel using a quadrature down conversion scheme. In this instance, the I channel and Q channel are orthogonal to each other. However, a phase error and a gain error are generated between I channel and the Q channel due to imperfect elements and the like, and these errors denote an I/Q mismatch.

In general, an ideal OFDM system generates a phase difference of 90 degrees between I channel and Q channel using a local oscillator. When the phase difference is not precisely 90 degrees, the phase error is generated. Also, each volume of I channel and Q channel signals has to be identical to each other, however, each volume differs due to the gain error.

In particular, there currently arises a need for a small-sized communication terminal with a relatively lower power consumption. Accordingly, a technology related with a direct-conversion receiver is urgently required, and the I/Q mismatch becomes a major cause adversely affecting an overall communication system in the direct-conversion receiver.

Thus, there is a need for an apparatus and method for receiving an OFDM signal that effectively estimates the I/Q mismatch, and corrects the estimated I/Q mismatch.

Disclosure of Invention

Technical Goals

An aspect of the present invention provides an apparatus and method for receiving an Orthogonal Frequency Division Multiplexing (OFDM) signal that calculates an I/Q parameter based on a timing synchronization error of the channel response, whereby communication is performed more effectively.

An aspect of the present invention provides an apparatus and method for receiving an OFDM signal that calculates an I/Q parameter considering a carrier frequency offset, whereby data is transmitted/received more effectively.

An aspect of the present invention provides an apparatus and method for receiving an OFDM signal that calculates an I/Q parameter using a complex conjugate pair of a channel frequency response, whereby communication is performed more accurately.

An aspect of the present invention provides an apparatus and method for receiving an OFDM signal that corrects an I/Q mismatch more accurately to transmit/receive data, whereby data is transmitted/received in a high speed.

Technical solutions

According to an aspect of the present invention, there is provided an apparatus for receiving an Orthogonal Frequency Division Multiplexing (OFDM) signal, which includes: a channel response estimating unit for receiving a frequency domain signal to estimate a channel response; an In-phase/Quadrature (I/Q) parameter calculating unit for calculating an I/Q parameter of the channel response based on a timing synchronization error of the channel response; and a channel response correcting unit for correcting the channel response using the I/Q parameter.

According to an aspect of the present invention, there is provided a method for receiving an OFDM signal, which includes: receiving a frequency domain signal to estimate a channel response; calculating an I/Q parameter of the channel response based on a timing synchronization error of the channel response; and correcting the channel response using the I/Q parameter.

Brief Description of Drawings

FIG. 1 is a block diagram illustrating an apparatus for receiving an Orthogonal Frequency Division Multiplexing (OFDM) signal according to an exemplary embodiment of the present invention;

FIG. 2 is a block diagram illustrating an example for correcting a channel response according to an exemplary embodiment of the present invention;

FIG. 3 illustrates a phase of a complex conjugate pair of a channel frequency response according to an exemplary embodiment of the present invention; and

FIG. 4 is a flowchart illustrating a method for receiving an OFDM signal according to an exemplary embodiment of the present invention.

Best Mode for Carrying Out the Invention

Reference will now be made in detail to embodiments of the present invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to the like elements throughout. The embodiments are described below in order to explain the present invention by referring to the figures.

FIG. 1 is a block diagram illustrating an apparatus for receiving an Orthogonal Frequency Division Multiplexing (OFDM) signal according to an exemplary embodiment of the present invention.

Referring to FIG. 1, the apparatus for receiving an OFDM signal includes a channel response estimating unit 100, an In-phase/Quadrature (I/Q) parameter calculating unit 110, and a channel response correcting unit 120.

The channel response estimating unit 100 receives a frequency domain signal and estimates a channel response. In this instance, the frequency domain signal may be generated such that a carrier frequency offset is corrected.

Also, although not shown in FIG. 1, the apparatus for receiving the OFDM signal according to the present exemplary embodiment of the invention may further include a Fast Fourier Transformer for transforming a received time domain signal into the frequency domain signal.

In this instance, the channel response estimating unit 100 may estimate the channel response through a Least Square (LS) scheme, a Linear Minimum Mean Square Error (LMMSE) scheme, or the like, using a training symbol.

In an OFDM communication system, various channel estimation schemes may be used. For example, a scheme for estimating a channel using a training symbol or a pilot signal, a scheme for estimating a blind channel without using the pilot signal, and the like may be used. Here, as examples for a channel estimating scheme using the training symbol, the LS scheme and the LMMSE scheme may be designated.

According to IEEE 802.11a, that is, a specification for an OFDM based-public Wireless LAN (WLAN) service, a packet includes two long training symbols. The training symbol includes a short training symbol and a long training symbol. The long training symbol is used by performing an inverse Fast Fourier Transformation with a predetermined sequence.

Also, the I/Q parameter calculating unit 110 calculates an I/Q parameter of the channel response considering a timing synchronization error of the channel response.

In this instance, the I/Q parameter calculating unit 110 may calculate the I/Q parameter according to an I/Q parameter calculation criterion generated by using a complex conjugate pair of a channel frequency response associated with the channel response.

In this instance, the I/Q parameter calculating unit 110 may calculate the I/Q parameter according to an I/Q parameter calculation criterion generated by using at least two complex conjugate pairs.

Also, the channel response correcting unit 120 corrects the channel response using the I/Q parameter.

FIG. 2 is a block diagram illustrating an example for correcting a channel response according to an exemplary embodiment of the present invention.

Referring to FIG. 2, $x_{tx}(t)$ of a time domain signal transmitted by a transmission end is represented by

[Equation 1]

$$x_{tx}(t) = a(t)\cos w_c t + b(t)\sin w_c t,$$

where a(t) and b(t) respectively denote an I channel value and Q channel value of a baseband signal transmitted by the transmission end, and w_c deno tes a frequency of a transmission signal.

A mixer 210 multiplies two signals by $x_{tx}(t)$, respectively, which is represented by

[Equation 2]

$$x_{LO,I}(t) = (1+\varepsilon)\cos((w_c + \Delta w_c)t + \theta), \text{ and}$$

$$x_{LO,Q}(t) = (1-\varepsilon)\sin((w_c + \Delta w_c)t + \theta),$$

where ε denotes a gain error, θ denotes a phase error, and Δw_c denotes a carrier frequency offset.

When the signal obtained by multiplying the two signals of Equation 2 by $x_{tx}(t)$ passes through low pass filters 221 and 222, respectively, a received baseband signal may be represented by

[Equation 3]

$$x_{BB,I}(t) = a(t)(1+\varepsilon)\cos\theta - b(t)(1+\varepsilon)\sin\theta$$, and

$$x_{BB,Q}(t) = -a(t)(1-\varepsilon)\sin\theta + b(t)(1-\varepsilon)\cos\theta$$.

When each of ε and θ is '0', $x_{BB,I}(t) = a(t)$, and $x_{BB,Q}(t) = b(t)$.

A received complex baseband signal may be represented by

[Equation 4]

$$x_{rx} = x_{BB,I} + jx_{BB,Q}$$,

where x_{rx} denotes a received time domain signal.

When Equation 4 is arranged by utilizing Equation 3, x_{rx} ma y be represented by

[Equation 5]

$$x_{rx} = \alpha \cdot x_{tx} + \beta \cdot x_{tx}^{*}$$,

$$\alpha = \cos\theta + j\varepsilon\sin\theta$$

$$\beta = \varepsilon\cos\theta - j\sin\theta$$,

where x_{tx} denotes a transmission signal transmitted by the transmission end.

Accordingly, x_{rx} of a received signal may be acquired by adding the product of x_{tx} of the transmission signal and α, and the product of a conjugate complex value of x_{rx} and β.

In this instance, each of α and β d enotes an I/Q parameter according to the I/Q mismatch.

Here, although not shown in FIG. 1, x_{rx} is converted into a digital signal using an analog to digital converter, and the digital signal may be expressed as r. Hereinafter, when it is assumed that x_{rx} is converted into the digital signal, the received baseband signal may be expressed as r. Also, the carrier frequency offset between carriers of a transmitter and receiver may exist. r_{cfo} of a sampled baseband time domain signal may be represented by

[Equation 6]

$$r_{cfo} = r \cdot e^{j2\pi f_{cfo} n / N},$$

where r denotes the received baseband signal, and r_{cfo} denotes a signal including the carrier frequency offset. In this instance, f_{cfo} denotes a carrier frequency offset normalized by a minimum interval (1/T_{SC}) between subcarriers, N denotes a number of subcarriers, and n denotes a sampled time index.

In this instance, a frequency offset correcting unit 230 estimates f_{cfo} of the carrier frequency offset, and corrects r_{cfo} according to the estimated result.

Specifically, $\hat{r}$ of a signal generated such that f_{cfo} of the carrier frequency offset is corrected may be represented by

[Equation 7]

$$\hat{r} = r_{cfo} \cdot e^{-j2\pi\hat{\varepsilon}n/N}$$

In this instance, $\hat{\varepsilon}$ may be represented by

[Equation 8]

$$\hat{\varepsilon} = \frac{N}{2\pi D}\arg\left(\sum_{k=0}^{D-1} r_{k+D} r_k^*\right),$$

where D denotes a length of the training symbol. For example, in the case of a communication system according to IEEE 802.11a, D may be '16' that is a length of the short training symbol, or '64' that is a length of the long training symbol. However, even when $\hat{\varepsilon}$ of the carrier frequency offset is accurately calculated in the case where the I/Q mismatch exists, a distortion is generated due to the interference between the subcarriers. Thus, both of the carrier frequency offset and the I/Q mismatch are preferably considered.

r_{cfo-iq} of the received baseband signal based on the carrier frequency offset and the I/Q mismatch is acquired by utilizing Equations 5 and 6, which may be represented by

[Equation 9]

$$r_{cfo-iq} = \alpha \cdot r_{cfo} + \beta \cdot r_{cfo}^{*}$$.

When utilizing Equations 6 and 9, r_{cfo-iq} of the received baseband signal based on the carrier frequency offset and the I/Q mismatch may be represented by

[Equation 10]

$$r_{cfo-iq} = \alpha \cdot r \cdot e^{j2\pi f_{cfo} n/N} + \beta \cdot r^{*} \cdot e^{-j2\pi f_{cfo} n/N}$$.

In this instance, when it is assumed that the frequency offset correcting unit 230 perfectly estimates f_{cfo} of the carrier frequency offset to thereby correct r_{cfo-iq} using $-f_{cfo}$ and f_{cfo}, respectively, Equation 10 may be represented by

[Equation 11]

$$r_1 = \alpha \cdot r + \beta \cdot r^{*} \cdot e^{-2j2\pi f_{cfo} n/N}$$,

$$r_2 = \alpha \cdot r \cdot e^{2j2\pi f_{cfo} n/N} + \beta \cdot r^{*}$$, and

$$r_2^{*} = \alpha^{*} \cdot r^{*} \cdot e^{-2j2\pi f_{cfo} n/N} + \beta^{*} \cdot r$$.

Referring to Equation 11, the frequency offset correcting unit 230 corrects r_{cfo-iq} using $-f_{cfo}$ to thereby generate r_1, and also corrects r_{cfo-iq} using f_{cfo} to thereb y generate r_2^{*} that is a complex conjugate value.

Also, each of Serial to Parallel (S/P) converters 241 and 242 transmits, to Fourier transformers 251 and 252, in parallel r_1 and r_2^* generated such that the carrier frequency offset is corrected.

Also, each of the Fourier transformers 251 and 252 transforms the received time domain signal into a frequency domain signal. Specifically, each of the Fourier transformers 251 and 252 transforms r_1 and r_2^* into the frequency domain signal.

Also, each of channel response estimating units 261 and 262 receives the frequency domain signal to estimate a channel response. In this instance, each of the channel response estimating units 261 and 262 may estimate the channel response through any one of the LS scheme, LMMSE scheme, and the like using the training symbol.

$\hat{r}$ of a signal generated such that an I/Q mismatch effect is corrected is acquired by utilizing Equation 11, which may be represented by

[Equation 12]

$$\hat{r} = \frac{\alpha^* \cdot r_1 - \beta \cdot r_2^*}{|\alpha|^2 - |\beta|^2}.$$

Specifically, the I/Q parameter (α and β) may be estimated using r_1 and r_2^* received during the long training symbol interval. In this instance, each of the channel response estimating units 261 and 262 may estimate the channel response through the LS scheme using r_1 and r_2^*, which may be represented by

[Equation 13]

$$h_1 = FFT(r_1) \cdot lts$$

$$h_2 = FFT(r_2^*) \cdot lts$$

In this instance, lts denotes a value in a frequency domain of the long training symbol, and h denotes the channel response. Here, $\hat{c}$ of the frequency response of the channel where the I/Q mismatch is corrected may be represented by

[Equation 14]

$$\hat{c} = \frac{\alpha^* \cdot h_1 - \beta \cdot h_2^*}{|\alpha|^2 - |\beta|^2}$$

Hereinafter, the case where τ of the timing synchronization error exists will be described with reference to FIG. 2. When τ of the timing synchronization error exists in the received signal, the time domain signal received during the length of the long training symbol is acquired by utilizing Equation 10, which may be represented by

[Equation 15]

$$r_{cfo-iq}(n-\tau) = \alpha \cdot r(n-\tau) \cdot e^{j2\pi f_{cfo}(n-\tau)/N} + \beta \cdot r^*(n-\tau) \cdot e^{-j2\pi f_{cfo}(n-\tau)/N}$$

Specifically, Equation 15 shows the received baseband signal including the I/Q mismatch based on the carrier frequency offset and the timing synchronization error.

Referring to Equation 11, the following Equation 16 may be acquired by utilizing Equation 15 using r_1 and r_2^*.

[Equation 16]

$$r_1 = \alpha \cdot r(n-\tau) \cdot e^{-j2\pi f_{cfo}\tau/N} + \beta \cdot r^*(n-\tau) \cdot e^{-j2\pi f_{cfo}(2n-\tau)/N}$$

$$r_2^* = \alpha^* \cdot r^*(n-\tau) \cdot e^{-j2\pi f_{cfo}(2n-\tau)/N} + \beta^* \cdot r(n-\tau) \cdot e^{-j2\pi f_{cfo}\tau/N}$$

.

In this instance, each of r_1 and r_2^* denotes a signal generated by correcting the carrier frequency offset using $-f_{cfo}$ and f_{cfo} in the case where the timing synchronization error exists.

In this instance, the channel response estimating units 261 and 262 may estimate the channel response through the LS scheme, and the estimated channel response may be represented by

[Equation 17]

$$\begin{aligned} h_{1,k} &= FFT(r_1) \cdot lts \\ &= FFT[\alpha \cdot r(n-\tau) \cdot e^{-j2\pi f_{cfo}\tau/N} + \beta \cdot r^*(n-\tau) \cdot e^{-j2\pi f_{cfo}(2n-\tau)/N}] \cdot lts \\ &= \alpha \cdot c_k \cdot e^{-j2\pi(k+f_{cfo})\tau/N} + lts \cdot \beta \cdot FFT[r^*(n-\tau) \cdot e^{-2j2\pi f_{cfo}n/N}] \cdot e^{j2\pi f_{cfo}\tau/N} \end{aligned}$$

$$\begin{aligned} h_{2,k} &= FFT(r_2^*) \cdot lts \\ &= FFT[\alpha^* \cdot r^*(n-\tau) \cdot e^{-j2\pi f_{cfo}(2n-\tau)/N} + \beta^* \cdot r(n-\tau) \cdot e^{-j2\pi f_{cfo}\tau/N}] \cdot lts \\ &= lts \cdot \alpha^* \cdot FFT[r^*(n-\tau) \cdot e^{-2j2\pi f_{cfo}n/N}] \cdot e^{j2\pi f_{cfo}\tau/N} + \beta^* \cdot c_k \cdot e^{-j2\pi(k+f_{cfo})\tau/N} \end{aligned}$$

,

where c_k denotes a channel frequency response. Specifically, each of the channel response estimating units 261 and 262 estimates the channel response by utilizing Equation 17 including $h_{1,k}$, $h_{2,k}$, r, lts, and the like.

Also, a I/Q parameter calculating unit 270 calculates the I/Q parameter of the channel response based on the timing synchronization error of the channel response.

When the channel frequency response generated such that the I/Q mismatch is corrected based on the timing synchronization error of the channel response is $\hat{c}_k$, which may be represented by

[Equation 18]

$$\hat{c}_k \cdot e^{-j2\pi(k+f_{cfo})\tau/N} = \frac{\alpha^* \cdot h_{1,k} - \beta \cdot h_{2,k}^*}{|\alpha|^2 - |\beta|^2}.$$

Referring to the left side of Equation 18, the product of $\hat{c}_k$ and $e^{-j2\pi(k+f_{cfo})\tau/N}$ of a phase rotation (value) is shown. The phase rotation value due to the timing synchronization error increases according to a subcarrier index (k) of an OFDM symbol. Thus, the similarity of the channel frequency response between neighboring subcarriers is less than that of the case where the timing synchronization error does not exist.

The phase rotation value due to the timing synchronization error varies according to characteristics of Fourier transformation in such a manner to have a number of cycles equivalent to the number of subcarriers (N) of the OFDM symbol. Also, a channel frequency response of a k-th subcarrier and a channel frequency response of an (N-k)-th subcarrier are a complex conjugate pair.

FIG. 3 illustrates a phase of a complex conjugate pair of a channel frequency response according to an exemplary embodiment of the present invention.

Referring to FIG. 3, the channel frequency response of the (N-k)-th subcarrier has a phase rotation value of θ_{N-k}. Also, the channel frequency response of the k-th subcarrier has a phase rotation value of θ_k.

Accordingly, the channel frequency response of the k-th subcarrier and the channel frequency response of the (N-k)-th subcarrier are a complex conjugate pair. Specifically, the complex conjugate pair of the channel frequency response has phase values having signs opposite from each other while having sizes different from each other.

Referring again to FIG. 2, the I/Q parameter calculating unit 270 may calculate the I/Q parameter using the complex conjugate pair of the channel frequency response associated with the channel response. Specifically, the I/Q parameter calculating unit 270 may calculate the I/Q parameter using characteristics of the phase (value) of the complex conjugate pair of the channel frequency response. A n offset of the phase rotation value is performed by multiplying the channel frequency response of the k-th subcarrier by the channel frequency response of the (N-k)-th subcarrier, which is represented by

[Equation 19]

$$\hat{C}_{k+1} \cdot \hat{C}_{N-(k+1)} \approx \hat{C}_k \cdot \hat{C}_{N-k}.$$

Referring to FIG. 19, it is found that, in the channel frequency response where the I/Q mismatch is corrected, similarity between a product of a complex conjugate pair and a product of another complex conjugate pair exists. Accordingly, when utilizing

FIG. 19, an I/Q parameter calculation criterion may be acquired, which is represented by

[Equation 20]

$$MSE = \sum_{k=1}^{N-1} \left| \hat{c}_{k+1} \cdot \hat{c}_{N-(k+1)} - \hat{c}_k \cdot \hat{c}_{N-k} \right|^2 ,$$

where denotes a mean square error.

The I/Q mismatch is a cause for reducing the similarity existing between the product of the complex conjugate pair and the product of the other complex conjugate pair in the channel frequency response T hus, correcting effects of the I/Q mismatch corresponds to ensuring the similarity between the product of the complex conjugate pair and the product of the other complex conjugate pair in the channel frequency response. Specifically, to correct the I/Q mismatch effect is to calculate an I/Q parameter for minimizing MSE of Equation 20.

Accordingly, the I/Q parameter calculating unit 270 may calculate the I/Q parameter according to the I/Q parameter calculation criterion such as Equation 20 generated using the complex conjugate pair of the channel frequency response.

Various schemes for calculating α and β for minimizing Equation 20 may exist. $\hat{c}_k$, $\hat{c}_{N-k}$, $\hat{c}_{k+1}$, and $\hat{c}_{N-(k+1)}$ may be expressed as h, and α and β may be expressed by utilizing Equation 18, and may be substituted for Equation 20, so that α and β for minimizing MSE of Equation 20 can be calculated. In this instance, α and β may be calculated by an iteration scheme, or a differential scheme.

Also, a channel response correcting unit 280 corrects a channel response using the calculated I/Q parameter. Referring again to Equation 18, the calculated α and β ma y be substituted for Equation 18, and accordingly, $\hat{C}_k$ of the channel frequency response generated such that the I/Q mismatch is corrected may be acquired based on the timing synchronization error.

Also, although not shown in FIG. 2, the apparatus for receiving the OFDM signal according to the present exemplary embodiment may include a data symbol correcting unit for correcting a received data symbol using the calculated I/Q parameter.

For example, in the case of a communication system according to IEEE 802.11a, the I/Q mismatch may affect the data symbol as well as the training symbol. In this instance, the data symbol correcting unit may correct the data symbol subsequently received after the training symbol based on the calculated I/Q parameter. A principle in which the channel response correcting corrects the channel response may be directly applicable to a process where the data symbol correcting unit corrects the data symbol.

F IG. 4 is a flowchart illustrating a method for receiving an OFDM signal according to an exemplary embodiment of the present invention.

Referring to FIG. 4, in operation S410, the method for receiving the OFDM signal according to the present exemplary embodiment receives a frequency domain signal to estimate a channel response.

In this instance, operation S410 may estimate the channel response through any one of the LS scheme and the LMMSE scheme using the training symbol.

In this instance, the frequency domain signal may be generated such that the carrier frequency offset is corrected.

Also, in operation S420, the method for receiving the OFDM signal according to the present exemplary embodiment calculates the I/Q parameter of the channel response based on the timing synchronization error of the channel response.

In this instance, operation S420 may calculate the I/Q parameter according to the I/Q parameter calculation criterion generated by using at least two complex conjugate pairs.

In this instance, operation S420 may calculate the I/Q parameter according to the I/Q parameter calculation criterion generated by

$$\sum_{k=1}^{N-1}\left|\hat{c}_{k+1}\cdot\hat{c}_{N-(k+1)}-\hat{c}_k\cdot\hat{c}_{N-k}\right|^2,$$

where ‘k’ denotes an index of a subcarrier, ‘N’ denotes a number of subcarriers, and $\hat{c}_k$ denotes a channel frequency response corresponding to a k-th subcarrier.

In this instance, operation S420 may calculate the I/Q parameter where an operation result of Equation 1 is minimized.

Also, in operation S430, the method for receiving the OFDM signal according to the present exemplary embodiment corrects the channel response using the calculated I/Q parameter.

Also, although not shown in FIG. 4, the method for receiving the OFDM signal according to the present exemplary embodiment may further include transforming a received time domain signal into the frequency domain signal using a Fourier transform scheme.

Also, although not shown in FIG. 4, the method for receiving the OFDM signal according to the present exemplary embodiment may further include correcting a received data symbol using the calculated I/Q parameter.

Portions of operations of FIG. 4, which are left undescribed, will be easily understood from descriptions of FIGS. 1 to 3, and thus their descriptions will be omitted.

The method for receiving the OFDM signal according to the above-described exemplary embodiments of the present invention may be recorded in computer-readable media including program instructions to implement various operations embodied by a computer. The media may also include, alone or in combination with the program instructions, data files, data structures, and the like. The media and program instructions may be those specially designed and constructed for the purposes of the present invention, or they may be of the kind well-known and available to those having skill in the computer software arts. Examples of computer-readable media include magnetic media such as hard disks, floppy disks, and magnetic tape; optical media such as CD ROM disks and DVD; magneto-optical media such as optical disks; and hardware devices that are specially configured to store and perform program instructions, such as read-only memory (ROM), random access memory (RAM), flash memory, and the like. Examples of program instructions include both machine code, such as produced by a compiler, and files containing higher level code that may be executed by the computer using an interpreter. The described hardware devices may be configured to act as one or more software modules in order to perform the operations of the above-described exemplary embodiments of the present invention.

As described above, according to the present invention, an I/Q parameter is calculated based on a timing synchronization error of the channel response, whereby communication is performed more effectively.

According to the present invention, an I/Q parameter is calculated considering a carrier frequency offset, whereby data is transmitted/received more effectively.

According to the present invention, an I/Q parameter is calculated using a complex conjugate pair of a channel frequency response, whereby communication is performed more accurately.

According to the present invention, an I/Q mismatch is corrected more accurately to transmit/receive data, whereby data is transmitted/received in a high speed.

Although a few embodiments of the present invention have been shown and described, the present invention is not limited to the described embodiments. Instead, it would be appreciated by those skilled in the art that changes may be made to these embodiments without departing from the principles and spirit of the invention, the scope of which is defined by the claims and their equivalents.

CLAIMS

1. An apparatus for receiving an Orthogonal Frequency Division Multiplexing (OFDM) signal, the apparatus comprising:

a channel response estimating unit for receiving a frequency domain signal to estimate a channel response;

an In-phase/Quadrature (I/Q) parameter calculating unit for calculating an I/Q parameter of the channel response based on a timing synchronization error of the channel response; and

a channel response correcting unit for correcting the channel response using the I/Q parameter.

2. The apparatus of claim 1, wherein the I/Q parameter calculating unit calculates the I/Q parameter according to an I/Q parameter calculation criterion generated by using a complex conjugate pair of a channel frequency response associated with the channel response.

3. The apparatus of claim 2, wherein the I/Q parameter calculation criterion is generated by using at least two complex conjugate pairs.

4. The apparatus of claim 2, wherein the I/Q parameter calculating unit calculates the I/Q parameter according to the I/Q parameter calculation criterion generated by

[Equation 1]

$$\sum_{k=1}^{N-1}\left|\hat{c}_{k+1}\cdot\hat{c}_{N-(k+1)}-\hat{c}_{k}\cdot\hat{c}_{N-k}\right|^{2},$$

where 'k' denotes an index of a subcarrier, 'N' denotes a number of subcarriers, and $\hat{c}_k$ denotes a channel frequency response corresponding to a k-th subcarrier.

5. The apparatus of claim 4, wherein the I/Q parameter calculating unit calculates the I/Q parameter where an operation result of Equation 1 is minimized.

6. The apparatus of claim 1, wherein the frequency domain signal is generated such that a carrier frequency offset is corrected.

7. The apparatus of claim 1, wherein the channel response estimating unit estimates the channel response through any one of a Least Square (LS) scheme and a Linear Minimum Mean Square Error (LMMSE) scheme using a training symbol.

8. The apparatus of claim 1, further comprising:

a Fourier transformer for transforming a received time domain signal into the frequency domain signal.

9. The apparatus of claim 1, further comprising:

a data symbol correcting unit for correcting a received data symbol using the calculated I/Q parameter.

10. A method for receiving an OFDM signal, the method comprising:

receiving a frequency domain signal to estimate a channel response;

calculating an I/Q parameter of the channel response based on a timing synchronization error of the channel response; and

correcting the channel response using the I/Q parameter.

11. The method of claim 10, wherein the calculating calculates the I/Q parameter according to an I/Q parameter calculation criterion generated by using a complex conjugate pair of a channel frequency response associated with the channel response.

12. The method of claim 11, wherein the I/Q parameter calculation criterion is generated by using at least two complex conjugate pairs.

13. The method of claim 11, wherein the calculating calculates the I/Q parameter according to the I/Q parameter calculation criterion generated by

[Equation 2]

$$\sum_{k=1}^{N-1}\left|\hat{c}_{k+1}\cdot\hat{c}_{N-(k+1)}-\hat{c}_{k}\cdot\hat{c}_{N-k}\right|^{2},$$

where 'k' denotes an index of a subcarrier, 'N' denotes a number of subcarriers, and $\hat{c}_k$ denotes a channel frequency response corresponding to a k-th subcarrier.

14. The method of claim 13, wherein the calculating calculates the I/Q parameter so that an operation result of Equation 2 is minimized.

15. The method of claim 10, wherein the frequency domain signal is generated such that a carrier frequency offset is corrected.

16. The method of claim 10, wherein the receiving estimates the channel response through any one of an LS scheme and an LMMSE scheme using a training symbol.

17. The method of claim 10, further comprising:

transforming a received time domain signal into the frequency domain signal using a Fourier transform scheme.

18. The method of claim 10, further comprising:

correcting a received data symbol using the calculated I/Q parameter.

19. A computer-readable recording medium storing a program for implementing the method of claim 10.

FIG. 1

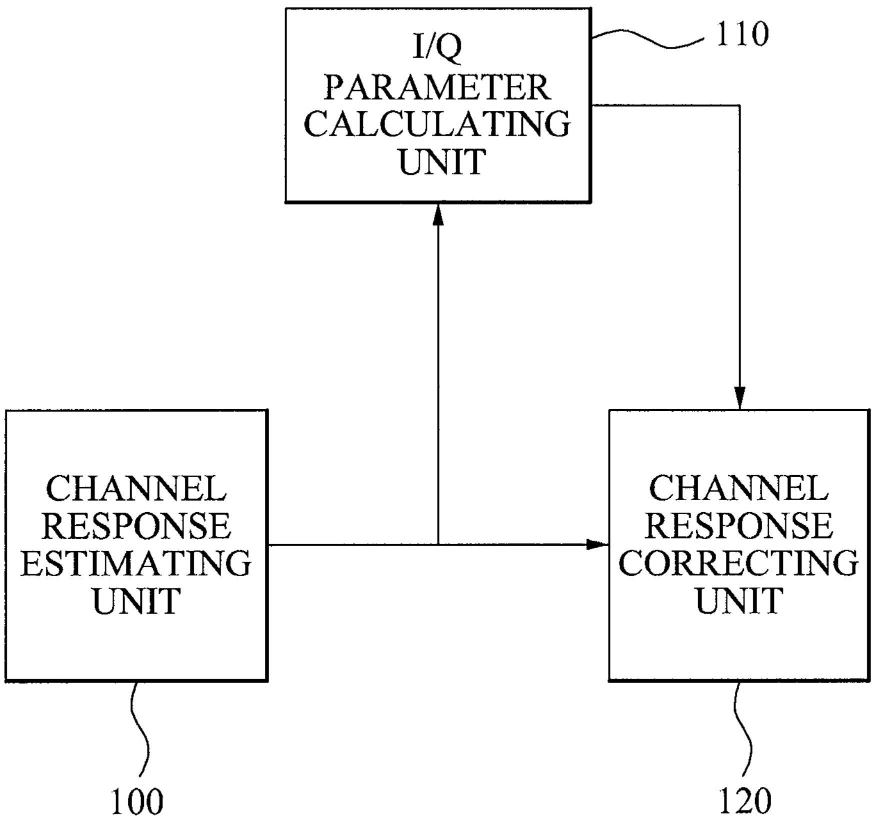

I/Q PARAMETER CALCULATING UNIT
110
CHANNEL RESPONSE ESTIMATING UNIT
CHANNEL RESPONSE CORRECTING UNIT
100
120

FIG. 2

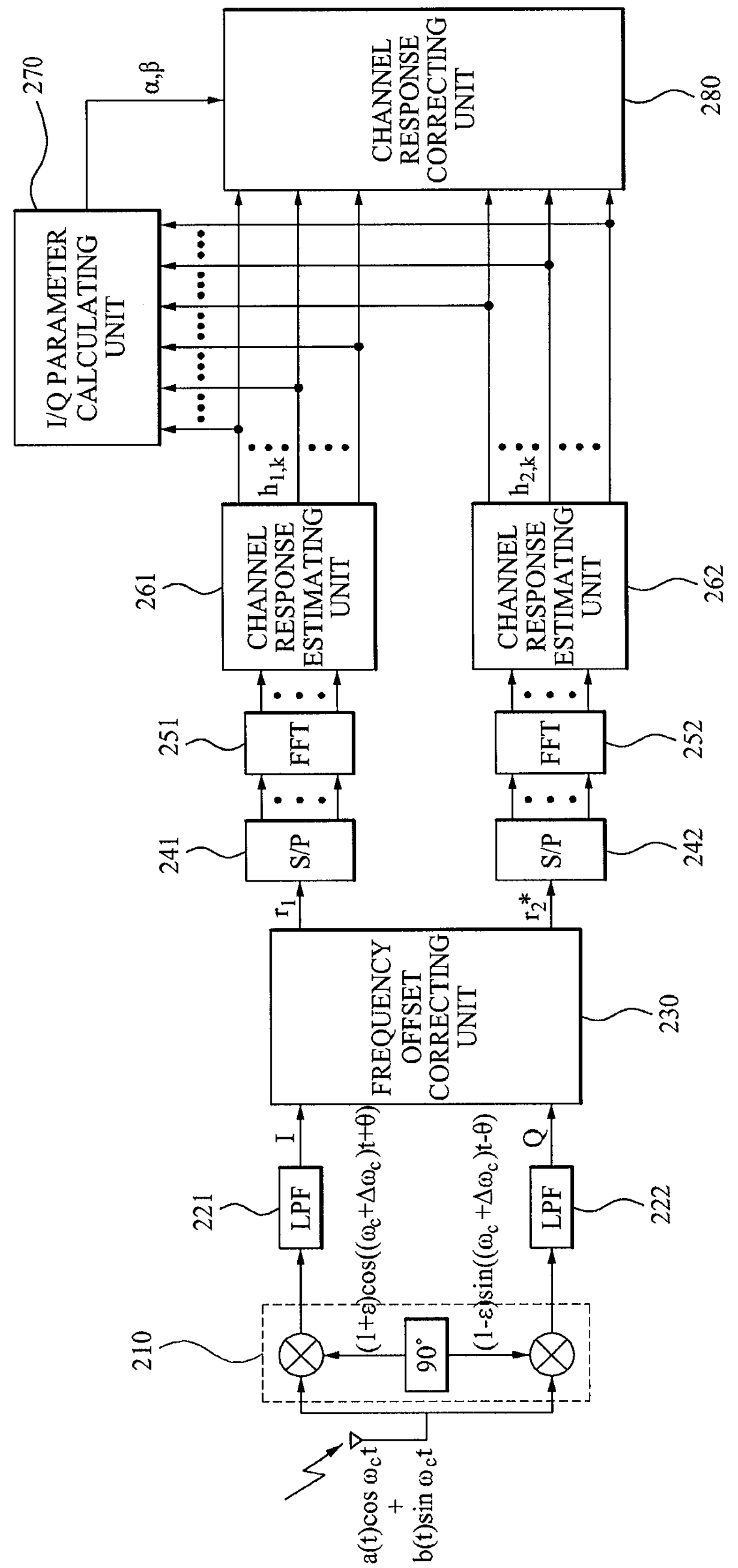

CHANNEL RESPONSE CORRECTING UNIT
280
270
α,β
I/Q PARAMETER CALCULATING UNIT
h1,k
h2,k
CHANNEL RESPONSE ESTIMATING UNIT
261
CHANNEL RESPONSE ESTIMATING UNIT
262
FFT
251
FFT
252
S/P
241
S/P
242
r1
r2*
FREQUENCY OFFSET CORRECTING UNIT
230
I
Q
LPF
221
LPF
222
(1+ε)cos((ωc+Δωc)t+θ)
(1-ε)sin((ωc+Δωc)t-θ)
90°
210
a(t)cos ωct
+
b(t)sin ωct

FIG. 3

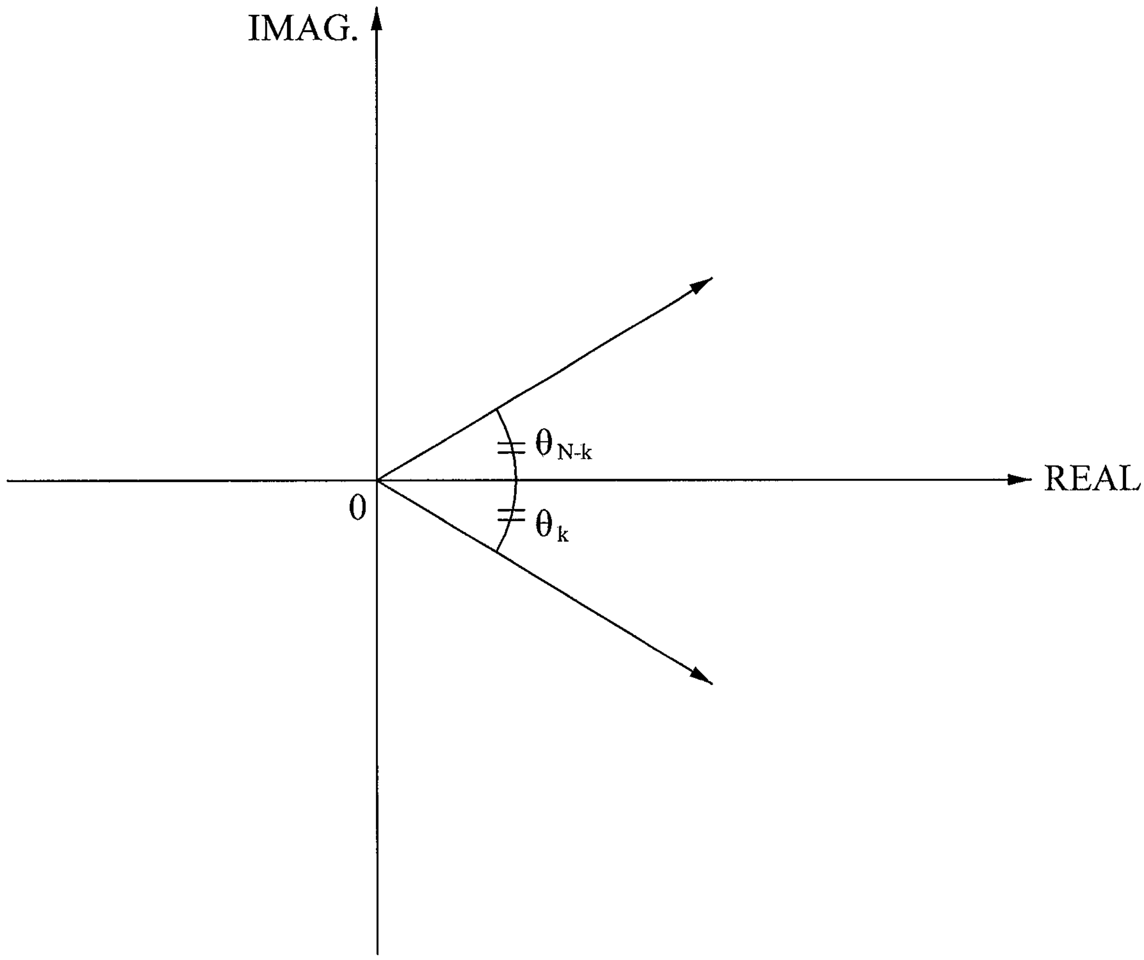
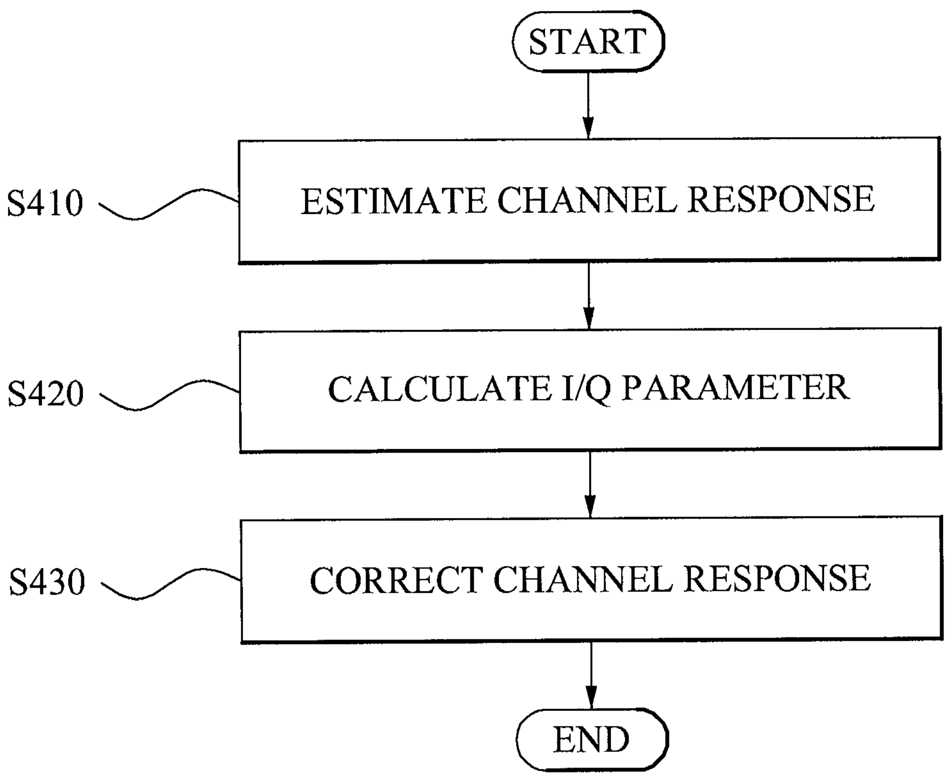


FIG. 4


START
S410
ESTIMATE CHANNEL RESPONSE
S420
CALCULATE I/Q PARAMETER
S430
CORRECT CHANNEL RESPONSE
END

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2008/000003

A. CLASSIFICATION OF SUBJECT MATTER

H04L 27/26(2006.01)i

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)
IPC 8 : H04L 27/26

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean Utility models and applications for Utility models since 1975
Japanese Utility models and applications for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
e-KIPASS(KIPO internal):
channel<and>response<and>(error<or>offset)<and>(compensa*)<and>(IQ)<and>(OFDM)<and>(MSE<or>LMM*)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005/0276354 A1 (SZU-LIN SU et al.) 15 DEC. 2005 See Page 1, Paragraph 7 - Page 2, Paragraph 14; Page 2, Paragraph 32 - Page 5, Paragraph 53; Figures 3,4,5,6.	1-19
A	KR10-2006-0108015 A (SAMSUNG ELEC. CO., LTD.) 17 OCT. 2006 See Page 7, Paragraph 8 - Page 8, Paragraph 20; Figures 7,8,9.	1-19
A	KR10-0578723 B1 (KOREA ELEC. TECH. INST.) 04 MAY 2006 See Page 3, line 24 - Page 6, Line 41; Figures 1,2,3,4.	1-19
A	WO 2005/071911 A1(QUALCOMM INC.) 04 AUG. 2005 See Page 4, Paragraph 22 - Page 5, Paragraph 26; Page 16, Paragraph 61 - Page 20, Paragraph 76; Figures 1,5,6,7,8.	1-19

☐ 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 application or patent 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 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
10 APRIL 2008 (10.04.2008)	**10 APRIL 2008 (10.04.2008)**

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Facsimile No. 82-42-472-7140

Authorized officer
PARK, SANG HYUN
Telephone No. 82-42-481-8263

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US2005276354A1	15.12.2005	CN1697432A	16.11.2005
		TW273786B	11.02.2007
		TW273786A	11.02.2007
KR1020061080150A	17.10.2006	US2006239368A1	26.10.2006
KR100578723B1	04.05.2006	NONE	
WO2005071911A1	04.08.2005	AR047378A1	18.01.2006
		AU2005207364A1	04.08.2005
		BR200506733A	02.05.2007
		CA2551988A1	04.08.2005
		CN1930841A	14.03.2007
		EP1706976A1	04.10.2006
		JP2007518363T2	05.07.2007
		KR2006107574A	13.10.2006
		NO20063570A	06.10.2006
		US2005152326A1	14.07.2005
		WO2005071911A1	04.08.2005