

DESCRIPTION

ADAPTIVE ARRAY APPARATUS

5 FIELD OF THE INVENTION

The present invention relates to an adaptive array apparatus that adaptively generates directivity patterns using a plurality of antennas, and in particular to a technique for improving the efficiency of signal processing
10 for generating directivity patterns.

BACKGROUND OF THE INVENTION

To raise transfer efficiency, digital communication devices transfer information by modulating a carrier wave
15 using a digital information signal (baseband signal) in recent years.

In digital communication, frequencies can be efficiently used by raising the transfer speed and utilizing each single frequency band for multiple channels
20 corresponding to multiple users.

The significant upsurge in the number of users of mobile communication services causes the shortage of frequency bands. The adaptive array method receives attention as a countermeasure against this problem.

25 The adaptive array method adaptively generates a directivity pattern using a plurality of antennas so that an

adaptive array apparatus transmits radio waves only to a specific user during transmission and receives radio waves only from a specific user during reception. Take, for example, an adaptive array apparatus that has four
5 communication subsystems that each include a transmission circuit, a reception circuit, and an antenna. The adaptive array apparatus respectively generates directivity patterns for transmission and reception by adjusting the amplitude and phase of the transmission signal in each communication
10 subsystem during transmission and by adjusting the amplitude and phase of the reception signal in each communication subsystem during reception. The adaptive array method is described in *Adaptive Signal Processing for Spatial Regions and Its Technical Applications* (in "Transactions of the
15 Institute of Electronics and Communication Engineers of Japan", Vol. J75-B-II No. 11, November 1992) and so is not described in detail here.

A path division multiple access (PDMA) communication method is proposed which allows a plurality of users to
20 simultaneously use the same frequency according to the adaptive array method. With the PDMA communication method, radio waves are transmitted and received using a plurality of directivity patterns which are each generated for one radio set (user). The PDMA communication method is
25 described in *Path Division Multiple Access (PDMA) Mobile Communication Method* (in "Shingakugihou", RSC93-84 (1994-



01), Institute of Electronics and Communication Engineers of Japan) and so is not described in detail here.

When the adaptive array method is applied to a mobile communication, a directivity pattern needs to be adjusted according to the change in a propagation circumstance. This is because the location of a user changes and the propagation circumstance changes with time. When analog processing that uses a conventional phase unit is applied to such a mobile communication, various problems concerning the precision, stability, and trackability are caused. Therefore, it is realistic that the adaptive array method is realized using digital signal processing.

The amplitude and phase of the signal dealt with in each communication subsystem are adjusted using the digital signal processing, as described above. In the case of a digital quadrature phase modulation, for instance, appropriate weights are assigned to the inphase component and the quadrature component of each symbol dealt with in each communication subsystem. The inphase component and quadrature component of each symbol are hereinafter simply referred to as an I component and a Q component, respectively. By doing so, the amplitude and phase of each symbol are adjusted. Accordingly, the signal processing is mainly composed of calculating the weighting factors corresponding to the I and Q components dealt with in each communication subsystem.

To adjust a directivity pattern according to the change in a propagation circumstance, the time interval for the adjustment needs to be shorter enough than time taken by the propagation circumstance to change. Therefore, for instance, it is preferable that the directivity pattern is adjusted in each symbol period. Also, the transfer speed of data in a recent mobile communication system becomes faster and the symbol period is shortened. In the PHS (personal handyphone system), for instance, the symbol period has been shortened to about five microseconds. Consequently, directivity patterns need to be adjusted in a short time.

The amount of signal processing necessary for the adaptive array method is significantly great because matrix calculations need to be performed to calculate the weighting factors described above. This causes a problem of how to perform the signal processing of such a large amount for the adaptive array method.

This problem becomes more pronounced when a plurality of users simultaneously use the same frequency according to the PDMA communication method to efficiently use frequencies. That is, the amount of signal processing increases in proportion to the number of users because the signal processing needs to be performed for each user.

It is difficult for one DSP (digital signal processor) to simultaneously process signals for a plurality of users due to the limitation of its signal processing

capacity. To cope with this problem, a plurality of DSPs may be used to perform signal processing necessary for the adjustment for a plurality of users in parallel. However, this inevitably increases the hardware scale and cost of an adaptive array apparatus.

In view of the stated problems, the object of the present invention is to provide an adaptive array apparatus which reduces the amount of signal processing necessary for the adjustment of a directivity pattern and minimizes the increase in the hardware scale and cost.

More specifically, the object of the present invention is to provide an adaptive array apparatus which appropriately performs the signal processing necessary for the adjustment for each user even if the number of users increases.

DISCLOSURE OF THE INVENTION

The object of the present invention can be achieved by an adaptive array apparatus, including a plurality of pairs of an antenna and a radio unit, for transmitting and receiving symbols using the radio units in each symbol period using combining coefficients, the combining coefficients being calculated for each radio unit and being used for forming a directivity pattern, the adaptive array apparatus including: a storing unit for storing symbols that are received by every radio unit in a plurality of symbol



periods, each radio unit receiving a symbol in each symbol period; a calculation unit for calculating combining coefficients corresponding to a given symbol period out of the plurality of symbol periods, based on symbols
5 corresponding to the given symbol period out of the stored symbols; and an interpolation unit for interpolating combining coefficients corresponding to symbol periods other than the given symbol period out of the plurality of symbol periods, based on the calculated combining coefficients.

10 With this construction, the calculation unit calculates combining coefficients for one symbol period out of every group of a plurality of symbol periods and the interpolation unit interpolates combining coefficients for the remaining symbol periods. Therefore, the amount of
15 signal processing necessary to calculate combining coefficients is reduced. This enables a DSP of poor throughput to perform the necessary signal processing. As a result, the increase in the hardware scale and cost of an adaptive array apparatus is minimized.

20 Here, the storing unit may store symbols that are received in the latest k symbol periods (k is no less than two), the calculation unit may calculate combining coefficients corresponding to a given symbol period out of every group of k symbol periods, there being $k-1$ symbol
25 periods between the given symbol period and a previous given symbol period for which the calculation unit calculated

combining coefficients, and the interpolation unit may interpolate combining coefficients corresponding to the k-1 symbol periods between the given symbol period and the previous given symbol period, based on the combining
5 coefficients calculated for the given symbol period and the previous given symbol period.

Here, the interpolation unit may linearly interpolate the combining coefficients corresponding to the k-1 symbol periods based on the combining coefficients calculated for
10 the given symbol period and the previous given symbol period.

With this construction, the interpolation unit linearly interpolates the combining coefficients corresponding to the k-1 symbol periods based on the
15 combining coefficients calculated for the given symbol period and the previous given symbol period. Therefore, combining coefficients are interpolated for each symbol period of the k-1 symbol periods. As a result, a directivity pattern is adjusted according to the change in
20 a propagation circumstance.

Here, the interpolation unit may use the combining coefficients corresponding to the previous given symbol period as the interpolated combining coefficients.

With this construction, the interpolation unit does
25 not need to calculate combining coefficients for each symbol periods of the k-1 symbol periods. As a result, the amount

of signal processing performed by the interpolation unit is reduced.

Here, the interpolation unit may use the combining coefficients corresponding to the given symbol period as the interpolated combining coefficients.

With this construction, the interpolation unit does not need to calculate combining coefficients for each symbol periods of the $k-1$ symbol periods. As a result, the amount of signal processing performed by the interpolation unit is reduced.

Here, the calculation unit may calculate combining coefficients used for forming a directivity pattern for one user radio in the given symbol period and calculate combining coefficients used for forming a directivity pattern for another user radio in a different given symbol period out of every group of k symbol periods, there being $k-1$ symbol periods between the different given symbol period and a previous different given symbol period for which the calculation unit calculates combining coefficients used for forming the directivity pattern for the other user radio, and the interpolation unit may interpolate combining coefficients corresponding to the $k-1$ symbol periods between the given symbol period and the previous given symbol period, based on the combining coefficients calculated in the given symbol period and the previous given symbol period, and interpolate combining coefficients corresponding

to the $k-1$ symbol periods between the different given symbol period and the previous different given symbol period, based on the combining coefficients calculated in the different given symbol period and the previous different given symbol period.

With this construction, the calculation unit calculates combining coefficients for respective user radios and the interpolation unit interpolates combining coefficients for respective user radios. Therefore, directivity patterns are simultaneously formed for respective user radios without increasing the amount of signal processing. The calculation unit calculates combining coefficients used for forming the directivity patterns for respective user radios in different symbol periods. As a result, the adaptive array apparatus of the present invention can be constructed with one DSP.

Here, each symbol may be expressed by an inphase component and a quadrature component, the storing unit may store inphase components and quadrature components of the symbols received in the latest k symbol periods, the calculation unit may calculate combining coefficients corresponding to inphase components and quadrature components of the symbols corresponding to the given symbol period out of the stored symbols, based on the inphase components and the quadrature components of the corresponding symbols, and the interpolation unit may

interpolate combining coefficients corresponding to the $k-1$ symbol periods between the given symbol period and the different given symbol period, based on the combining coefficients calculated in the given symbol period and the different given symbol period.

Here, the calculation unit may calculate combining coefficients used for forming a directivity pattern for a direct wave in the given symbol period and calculates combining coefficients used for forming a directivity pattern for an indirect wave in a different given symbol period out of every group of k symbol periods, there being $k-1$ symbol periods between the different given symbol period and a previous different given symbol period for which the calculation unit calculated combining coefficients used for forming the directivity pattern for the indirect wave, and the interpolation unit may interpolate the combining coefficients corresponding to the $k-1$ symbol periods between the given symbol period and the different given symbol period, based on the combining coefficients calculated in the given symbol period and the previous given symbol period, and interpolates combining coefficients corresponding to $k-1$ symbol periods between the different given symbol period and the previous different given symbol period, based on the combining coefficients calculated in the different given symbol period and the previous different given symbol period. With this construction, the path

diversity is realized without difficulty.

Here, the calculation unit and the interpolation unit may include a programmable digital signal processor. As a result, the increase in the hardware scale and cost of an adaptive array apparatus is minimized.

The stated object of the present invention can also be achieved by an adaptive array apparatus, including a plurality of pairs of an antenna and a radio unit, for transmitting and receiving symbols using the radio units in each symbol period using combining coefficients, the combining coefficients being calculated for each radio unit and being used for forming directivity patterns which each correspond to one of a plurality of user radios, the adaptive array apparatus including: a storing unit for storing symbols that are received by every radio unit in the latest k symbol periods (k is no less than three), each radio unit receiving a symbol in each symbol period; a calculation unit for calculating combining coefficients corresponding to a given symbol period out of every group of k symbol periods, based on symbols corresponding to the given symbol period out of the stored symbols, there being $k-1$ symbol periods between the given symbol period and a previous given symbol period for which the calculation unit calculated combining coefficients; and an interpolation unit for interpolating combining coefficients corresponding to the $k-1$ symbol periods between the given symbol period and

the previous given symbol period, based on the calculated combining coefficients corresponding to the given symbol period and the previous given symbol period.

Here, the variable k may be no less than a number of symbol periods that equates to the time taken by the calculation unit to calculate combining coefficients for all of the plurality of user radios.

With this construction, the calculation unit does not need to simultaneously use a plurality of DSPs. Therefore, the calculation unit calculates combining coefficients for a plurality of radio units with one DSP. Also, even if a DSP of a poor throughput is used, combining coefficients are calculated for a plurality of user radios by setting the variable k in consideration of the throughput of the DSP.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing the construction of the adaptive array apparatus of Embodiment 1 of the present invention;

Fig. 2 shows a state where a symbol is adjusted by assigning weights to the symbol;

Fig. 3 shows a state where a plurality of directivity patterns are generated to allow a plurality of users to simultaneously use the same frequency;

Fig. 4 is a block diagram showing the detailed constructions of the reception adjustment units and the

control unit of the adaptive array apparatus;

Fig. 5 is the timing chart of the calculation processing of the control unit 50;

Fig. 6 is a flowchart showing the simplified processing of the control unit 50 to realize the timings of the calculation processing shown in Fig. 5;

Fig. 7 is a detailed flowchart of the basic flow shown in Fig. 6;

Fig. 8 shows an example where linear interpolation is performed;

Fig. 9 is a flowchart showing the detailed process for calculating weighting factors at a current symbol time (the direct calculation processing) in step 72 in Fig. 7;

Fig. 10 is a timing chart showing the timings of the calculation processing of the control unit 50 of Embodiment 2;

Fig. 11 is the timing chart of the calculation processing of the control unit 50 of Embodiment 3; and

Fig. 12 shows modifications of the adaptive array apparatuses of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

<Embodiment 1>

<Simplified Construction of Adaptive Array Apparatus>

Fig. 1 is a block diagram showing the construction of the adaptive array apparatus of Embodiment 1 of the present

invention. The adaptive array apparatus of the present embodiment includes radio communication units 10, 20, 30, and 40, antennas 17, 27, 37, and 47, reception adjustment units 18, 28, 38, and 48, transmission adjustment units 19, 29, 39, and 49, and a control unit 50. This adaptive array apparatus is provided as a base station for mobile communication using devices such as digital portable telephones. The radio communication unit 10 includes a modulator 11, a transmission circuit 12, a switch 13, a reception circuit 15, and a demodulator 16.

In the radio communication unit 10, the modulator 11 modulates a baseband signal that is inputted from the control unit 50 via the transmission adjustment unit 19 to convert it into an intermediate frequency signal (hereinafter abbreviated to "IF signal"). The transmission circuit 12 converts the IF signal received from the modulator 11 into a high-frequency signal (hereinafter abbreviated to "RF signal"), and amplifies the RF signal to the transmission output level. The switch 13 switches between transmission and reception. The reception circuit 15 converts a reception signal into an IF signal. The demodulator 16 demodulates the IF signal that is inputted from the reception circuit 15 to convert it into the baseband signal. Here, the modulator 11 and the demodulator 16 may use any type of digital modulation and demodulation method, such as $\pi/4$ shift QPSK (Quadrature Phase Shift Keying). In

the present embodiment, the baseband signal that has been generated by the demodulator 16 is time series data represented by I component and Q component of each symbol.

The reception adjustment unit 18 adjusts the
5 amplitude and phase of reception baseband signal that is inputted from the demodulator 16 according to the instructions from the control unit 50. More specifically, when an I component and a Q component of a reception baseband signal are inputted for one symbol from the
10 demodulator 16, the reception adjustment unit 18 adjusts the amplitude and phase of the symbol by respectively assigning weights to the I component and the Q component.

Fig. 2 shows a state where a symbol is adjusted by assigning weights to the symbol. In this drawing, a symbol
15 that has been generated by the demodulator 16 and a symbol to which weights have been assigned are shown on an I-Q coordinate plane. I_1 and Q_1 respectively represent the I and Q components of the symbol generated by the demodulator 16. WI_1 and WQ_1 respectively represent the I and Q
20 components of the symbol to which weights have been assigned by the reception adjustment unit 18. As shown in this drawing, the reception adjustment unit 18 adjusts the amplitude and phase of each symbol by respectively assigning weights to the I component and the Q component of each
25 symbol. The control unit 50 determines the weighting factors used to respectively assign weights to the I

component and the Q component.

The transmission adjustment unit 19 adjusts the amplitude and phase of a transmission baseband signal inputted from the control unit 50 to generate a directivity pattern. This adjustment is performed in the same way as shown in Fig. 2.

The radio communication units 20, 30, and 40 all have the same construction as the radio communication unit 10 and so will not be described here.

The control unit 50 includes a programmable digital signal processor as its main element and realizes the following functions by executing a program. That is, the control unit 50 controls the transmission and reception operations of the radio communication units 10-40. The control unit 50 also calculates weighting factors corresponding to the I and Q components of each symbol dealt with in each radio communication unit and outputs the calculated weighting factors to the reception adjustment unit 18 and the transmission adjustment unit 19 to generate a plurality of directivity patterns. The plurality of directivity patterns are each directivity pattern that is generated for one user in the case where a plurality of users simultaneously use the same frequency. Fig. 3 shows a state where a plurality of directivity patterns are generated. In this drawing, four user radio sets "a"-"d" (hereinafter abbreviated to users "a"-"d") simultaneously

use the same frequency.

As described above, in each symbol period, the control unit 50 calculates weighting factors corresponding to the I and Q components of the symbol dealt with in each radio communication unit for one user. In the present embodiment, the processing amount of the control unit 50 is reduced to increase the efficiency of the control unit 50. That is, when four users simultaneously use an adaptive array apparatus as shown in Fig. 3, the control unit 50 allocates one symbol period out of every four symbol periods to the user "a" as a period for processing signals for the user "a". In the allocated symbol period, for the user "a", the control unit 50 calculates weighting factors for the allocated symbol period based on the symbol received in the allocated symbol period, and interpolates weighting factors for three other symbol periods based on calculated weighting factors. The calculation of weighting factors based on received symbols and the interpolation of weighting factors based on calculated weighting factors are hereinafter referred to as direct calculation processing and indirect calculation processing, respectively. If weighting factors are calculated for each user in each symbol period by the direct calculation processing, the control unit 50 needs to perform an enormous amount of processing. Therefore, in the present embodiment, the processing amount of the control unit 50 is reduced to increase the efficiency of the control

unit 50.

Similarly, the control unit 50 allocates another symbol period out of every four symbol periods to the user "b" and calculates weighting factors for the user "b" by the direct calculation processing and the indirect calculation processing. The remaining two symbol periods out of every four symbol periods are respectively allocated to the users "c" and "d" and the same operation is performed.

As described above, the control unit 50 needs to calculate weighting factors for each user. This is because each of the users "a"-"d" requires a unique directivity pattern, as shown in Fig. 3. To efficiently perform the signal processing concerning weighting factors which represent unique directivity patterns, the control unit 50 cyclically allocates symbol periods to each user.

<Construction of Main Part of Adaptive Array Apparatus>

Fig. 4 is a block diagram showing the detailed constructions of the reception adjustment units and the control unit of the adaptive array apparatus shown in Fig. 1.

The reception adjustment units 18, 28, 38, and 48 all have the same construction and the following description takes the reception adjustment unit 18 as an example.

The reception adjustment unit 18 includes an I buffer 101, a Q buffer 102, and multipliers 103 and 104.

The I buffer 101 sequentially renews and holds I components of the latest four symbols that are inputted from the demodulator 16. The I components of the latest four symbols are expressed by $I_1(t-3\Delta t)$, $I_1(t-2\Delta t)$, $I_1(t-\Delta t)$, and $I_1(t)$. Here, "1" of I_1 corresponds to the radio communication unit 10, "t" represents a symbol time, and Δt represents a symbol period. The I buffer 101 outputs the I component $I_1(t)$ and the control unit 50 can randomly read I component from the I buffer 101. Note that it is enough for the I buffer 101 to store pieces of data whose number is obtained by adding one to the number of symbols for which interpolation processing (indirect calculation processing) is performed. In this embodiment, the number of pieces of data held by the I buffer 101 is set to four.

The Q buffer 102 holds Q components of the latest four symbols that are inputted from the demodulator 16, as the I buffer 101. The Q components of the latest four symbols are expressed by $Q_1(t-3\Delta t)$, $Q_1(t-2\Delta t)$, $Q_1(t-\Delta t)$, and $Q_1(t)$.

The multiplier 103 assigns a weight to an I component. That is, the multiplier 103 multiplies an I component inputted from the demodulator 16 by the corresponding weighting factor given by the control unit 50.

The multiplier 104 assigns a weight to a Q component. That is, the multiplier 104 multiplies a Q component

inputted from the demodulator 16 by the corresponding weighting factor given by the control unit 50.

The reception adjustment units 28, 38, and 48 perform the same operation as the reception adjustment unit 18.

5 The control unit 50 includes a W buffer 51 and cyclically allocates symbol periods to each user. In each symbol period allocated to one user, for the user, the control unit 50 performs the direct calculation processing to calculate weighting factors corresponding to the symbol
10 received in the allocated symbol period and performs the indirect calculation processing to calculate weighting factors corresponding to symbols received in the remaining three symbol periods. The W buffer 51 stores weighting factors of one symbol that have been previously calculated
15 by the direct calculation processing, for each component dealt with in each radio communication unit. The weighting factors stored in the W buffer 51 are used for the indirect calculation processing.

20 Specific timings of calculation processing of the control unit 50 are described below.

<Timing of Calculation Processing of Control Unit 50>

Fig. 5 is the timing chart of the calculation processing of the control unit 50. This drawing is based on
25 the assumption that the adaptive array apparatus is shared by four users according to the PDMA communication method.

The "symbol time" row in this drawing gives symbol times $t_0, t_1, t_2, \dots$. One symbol period is set to about five microseconds when the adaptive array apparatus of the present embodiment is used as a base station of the PHS (personal handyphone system).

The "output from all I and Q buffers" row in this drawing gives the output data $D(t)$ outputted from all I and Q buffers in each symbol time. The output data $D(t_0)$ outputted at the symbol time t_0 is expressed by

$D(t_0) = (I_1(t_0), I_2(t_0), I_3(t_0), I_4(t_0), Q_1(t_0), Q_2(t_0), Q_3(t_0), Q_4(t_0)).$

The "calculation processing of control unit 50" row shows which user is allocated the corresponding symbol period and shows the weighting factors calculated by the direct calculation processing. In this example, each symbol period is cyclically allocated to users in the pattern of a, b, c, d, a, b, c, d, ... For instance, the symbol period at the symbol time t_4 is allocated to the user "a". In this symbol period, the weighting factors corresponding to I and Q components dealt with in all radio communication units are calculated to form the directivity pattern of the user "a". More specifically, in this symbol period, the control unit 50 calculates weighting factors corresponding to four symbols received at the symbol times t_1 - t_4 by the direct and indirect calculation processing. To calculate weighting factors, the direct calculation processing is performed for

the symbol time t_4 and the indirect calculation processing is performed for the symbol times t_1 - t_3 .

The "weighting factor for user 'a'" row gives the weighting factors corresponding to each symbol that are calculated to form a directivity pattern for the user "a". For instance, weighting factors corresponding to the symbol times t_1 - t_4 are calculated in the symbol period at the symbol time t_4 . In this drawing, the weighting factors, $W_{Ia1}(t)$ to $W_{Ia4}(t)$ and $W_{Qa1}(t)$ to $W_{Qa4}(t)$, are calculated by the direct calculation processing and the weighting factors, $X_3(=X_{Ia1}(t)$ to $X_{Ia4}(t)$ and $X_{Qa1}(t)$ to $X_{Qa4}(t))$, are calculated by the indirect calculation processing.

The "weighting factor for user 'b'" row gives the weighting factors corresponding to each symbol that are calculated to form a directivity pattern for the user "b". For instance, weighting factors corresponding to the symbol times t_2 - t_5 are calculated in the symbol period t_5 .

The "weighting factor for user 'c'" and "weighting factor for user 'd'" rows are the same as the "weighting factor for user 'a'" and "weighting factor for user 'b'" rows.

<Flow of Overall Processing of Control Unit 50>

Fig. 6 is a simplified flowchart showing the processing of the control unit 50 to realize the timings of the calculation processing shown in Fig. 5. This drawing is

also based on the assumption that the adaptive array apparatus of the present embodiment is shared by four users according to the PDMA communication method.

The basic flow in each step in this flowchart shows
5 signal processing performed by the control unit 50 in one symbol period. In each step, the control unit 50 calculates weighting factors corresponding to four symbols by the direct and indirect calculation processing to form a directivity pattern for one user. The control unit 50
10 performs the processing of the basic flow by cyclically changing the user for which weighting factors are calculated (steps 61-64). The basic flow is described in detail below.

15 <Signal Processing of Control Unit 50 in One Symbol Period (Basic Flow)>

Fig. 7 is a detailed flowchart of the basic flow shown in Fig. 6. The following description concerns the case of the user "a".

20 As shown in this drawing, the control unit 50 reads I and Q components obtained at the current symbol time "t" ($I1(t)$ - $I4(t)$, $Q1(t)$ - $Q4(t)$) from I and Q buffers of all radio communication units (step 71). Then the control unit 50 calculates weighting factors corresponding to the current
25 symbol from the read I and Q components by the direct calculation processing (step 72), and stores the calculation

results ($W_{Ia1}(t)$ to $W_{Ia4}(t)$ and $W_{Qa1}(t)$ to $W_{Qa4}(t)$) into the W buffer 51 (step 73). The control unit 50 has all multipliers calculate combined signals for the user "a" at the current symbol time "t" using the calculated weighting factors (step 74). The combined signals, $Y_{Ia}(t)$ and $Y_{Qa}(t)$, for the user "a" at the symbol time "t" are obtained by

$$Y_{Ia}(t) = \sum W_{Iai}(t) * I_i(t), \quad Y_{Qa}(t) = \sum W_{Qai}(t) * Q_i(t)$$

where $i=1-4$. The combined signals represent a symbol received at the symbol time "t" using the directivity pattern of the user "a". That is, the combined signals represent the received symbol where received signals of other users are removed.

Then the control unit 50 reads weighting factors that have been previously calculated by the direct calculation processing from the W buffer 51 (step 75). In the case of the timing chart shown in Fig. 5, because the W buffer 51 stores weighting factors that have been calculated four symbol times before, the control unit 50 reads $W_{Ia1}(t-4*At)$ to $W_{Ia4}(t-4*At)$ and $W_{Qa1}(t-4*At)$ to $W_{Qa4}(t-4*At)$ from the W buffer 51. The control unit 50 calculates weighting factors corresponding to three symbols at the symbol times $(t-At)$, $(t-2*At)$, and $(t-3*At)$ by performing the indirect calculation processing, which is to say interpolation, using the weighting factors read from the W buffer and the weighting factors that have been calculated by the direct calculation processing at the current symbol time "t" (step

76).

Fig. 8 shows the example where linear interpolation is performed. Among indirect calculation processing performed at the symbol time t_4 , this drawing shows a state where the weighting factors $XIa_1(t_1)$, $XIa_1(t_2)$, and $XIa_1(t_3)$ corresponding to symbols at the symbol times t_1 , t_2 , and t_3 are calculated using the weighting factors $WIa_1(t_4)$ and $WIa_1(t_0)$ that correspond to the I components received by the radio communication unit 10.

The weighting factors $XQ_1(t_1)$, $XQ_1(t_2)$, and $XQ_1(t_3)$ that correspond to the Q components received by the radio communication unit 10 are calculated by the same interpolation. The weighting factors corresponding to the I and Q components received by the radio communication units 20, 30, and 40 are also interpolated in the same way.

The control unit 50 further reads symbols obtained before the current symbol time, which is to say I and Q components that correspond to three symbols at symbol times $(t-\Delta t)$, $(t-2\Delta t)$, and $(t-3\Delta t)$, from I and Q buffers of all radio communication units (step 77). Then the control unit 50 calculates combined signals given below from the read I and Q components and the weighting factors obtained by performing the indirect calculation processing. Note that in the following equations, $i=1-4$.

The combined signals one symbol time before are $YIa(t-\Delta t) = EXIi(t-\Delta t) * Ii(t-\Delta t)$, and

$$YQa(t-\Delta t) = \Sigma XQi(t-\Delta t) * Qi(t-\Delta t).$$

The combined signals two symbol times before are

$$YIa(t-2*\Delta t) = \Sigma XIi(t-2*\Delta t) * Ii(t-2*\Delta t), \text{ and}$$

$$YQa(t-2*\Delta t) = \Sigma XQi(t-2*\Delta t) * Qi(t-2*\Delta t).$$

6 The combined signals three symbol times before are

$$YIa(t-3*\Delta t) = \Sigma XIi(t-3*\Delta t) * Ii(t-3*\Delta t), \text{ and}$$

$$YQa(t-3*\Delta t) = \Sigma XQi(t-3*\Delta t) * Qi(t-3*\Delta t).$$

10 In this manner, the control unit 50 performs the processing in the basic flow for the user "a" during the symbol period at the symbol time "t". The processing in the basic flow is also performed for the users "b", "c", and "d" during the symbol periods at the symbol times (t+1), (t+2), and (t+3), respectively.

15 It should be noted here that although the control unit 50 performs linear interpolation in step 76, any other interpolation method may be performed in step 76.

20 In step 76, for instance, the control unit 50 may interpolate weighting factors by adding the weighting factors read from the W buffer 51, which is to say $WIa1(t-4*\Delta t)$ to $WIa4(t-4*\Delta t)$ and $WQa1(t-4*\Delta t)$ to $WQa4(t-4*\Delta t)$, to the weighting factors corresponding to the current symbol, which is to say $WIa1(t)$ to $WIa4(t)$ and $WQa1(t)$ to $WQa4(t)$, dividing the addition result by two to obtain mean values, and using the mean values as the weighting factors

25 corresponding to three symbols at the symbol times (t-Δt), (t-2*Δt), and (t-3*Δt).

Also, the control unit 50 may interpolate weighting factors by using the weighting factors corresponding to the current symbol, which is to say $W_{Ia1}(t)$ to $W_{Ia4}(t)$ and $W_{Qa1}(t)$ to $W_{Qa4}(t)$, as the weighting factors corresponding to three symbols at the symbol times $(t-\Delta t)$, $(t-2\Delta t)$, and $(t-3\Delta t)$. In this case, the control unit 50 does not need to read the weighting factors that have been previously calculated from the W buffer 51 in step 75. As a result, the process in this step can be omitted.

Furthermore, the control unit 50 may interpolate weighting factors by using the weighting factors corresponding to the current symbol, which is to say $W_{Ia1}(t)$ to $W_{Ia4}(t)$ and $W_{Qa1}(t)$ to $W_{Qa4}(t)$, as the weighting factors corresponding to three symbol times following the current symbol time. In this case, the I and Q buffers does not need to store symbols corresponding to the symbol times $(t-\Delta t)$, $(t-2\Delta t)$, and $(t-3\Delta t)$.

<Detailed Flow of Direct Calculation Processing>

Fig. 9 is a flowchart showing the detailed process for calculating weighting factors corresponding to the current symbol time (the direct calculation processing) in step 72 in Fig. 7.

The processing in this drawing uses a publicly known technique that concerns an adaptive array method using a Kalman filter. This technique is described in detail in

Analysis of Adaptive Antenna Using Kalman Filter (in
"Transactions of the Institute of Electronics and
Communication Engineers of Japan", B-II, Vol. J75-B-II No.
11, pp835-843, November 1992). Therefore, this technique is
5 briefly described below.

The control unit 50 performs initialization when the
initialization has not been performed (steps 91 and 92).
During the initialization, the initial value $P(0)$ of the
estimation error dispersion matrix of a Kalman filter and
10 the initial value $W(0)$ of the weighting factor matrix are
set. In this embodiment, the initial value $P(0)$ is $C \cdot I$ (C
is a constant and I is a unit matrix of 4×4) and the initial
value $W(0)$ is 4×1 vector shown in this drawing. In this
case, the weighting factor matrix $W(t)$ is expressed as the
15 4×1 vector shown in this drawing.

The control unit 50 then sets I and Q components
corresponding to the symbol time " t " inputted from the I and
 Q buffers as input signals (step 93) and sets the reference
signal $d(t)$ (step 94). Here, the reference signal $d(t)$ is
20 the estimated waveform of received signals that should be
obtained from a specific user. When signals received at the
symbol time " t " is known data, such as the preamble or the
user ID of received data, the control unit 50 sets the
waveform of the received signals as the estimated waveform.
25 On the other hand, when the signals received at the symbol
time " t " is not known data, the control unit 50 temporarily

determines the received data and sets the waveform of the received data as the estimated waveform. Here, the received signal $Y(t)$ that is temporarily determined by the control unit 50 is obtained by multiplying I and Q components
5 corresponding to the symbol time "t" by previously calculated weighting factors and by combining the multiplied I and Q components.

The control unit 50 then calculates Kalman gains and the error of the estimated waveform and renews weighting
10 factors and correlation matrixes (steps 95-98), as shown in this drawing. The process in steps 95-98 is performed with a publicly known technique where a recursive least square (RLS) method (RLS algorithm) is applied to a Kalman filter and so is not described here.

15 In this manner, weighting factors are calculated by the direct calculation processing.

As described above, the adaptive array apparatus of the present embodiment cyclically allocates symbol periods to a plurality of users in the case of the PDMA
20 communication method. In one symbol period, the adaptive array apparatus performs the direct calculation processing to calculate weighting factors of the symbol corresponding to one out of predetermined symbol periods and performs the indirect calculation processing to calculate weighting
25 factors corresponding to the other symbol periods. As a result, the amount of signal processing for calculating

weighting factors are considerably reduced, with the weighting factors corresponding to each symbol being renewed for all users.

5 <Embodiment 2>

The simplified construction of the adaptive array apparatus of the present embodiment is almost the same as that of the adaptive array apparatus of Embodiment 1 shown in Fig. 1. Therefore, the following description centers on
10 the different aspect between these adaptive array apparatuses.

The different aspect is the way to cyclically allocate symbol periods to a plurality of users. The adaptive array apparatus of the present embodiment is
15 constructed to cyclically allocate units of two symbol periods to a plurality of users.

To do so, I and Q buffers in Embodiment 2 is different from those in Embodiment 1, and sequentially renews and holds data that is inputted from the demodulator
20 at the latest eight symbol times.

Also, the control unit 50 of Embodiment 2 is different from that of Embodiment 1 and, in successive two symbol periods, performs the direct calculation processing for one symbol and performs the indirect calculation
25 processing for remaining seven symbols.

Fig. 10 is a timing chart showing the timings of the

calculation processing of the control unit 50. In this drawing, every unit of two symbol periods is allocated to one user, different from the timing chart shown in Fig. 5. For instance, symbol periods at the symbol times t_0 and t_1 are allocated to the user "a", symbol periods at the symbol times t_2 and t_3 are allocated to the user "b". Similarly, a unit of symbol periods at two symbol times is allocated to each of the users "c" and "d".

In two symbol periods, the control unit 50 performs the direct calculation processing to calculate weighting factors corresponding to one out of eight symbols and performs the indirect calculation processing to calculate weighting factors corresponding to the remaining seven symbols. Although the ratio of symbols for which the indirect calculation processing is performed rises, the period in which signals are processed for one user doubles in comparison with Embodiment 1. Consequently, even if a DSP of the control unit 50 has a poor throughput, the control unit 50 can calculate weighting factors corresponding to each symbol for a plurality of users by the direct and indirect calculation processing.

<Embodiment 3>

In this embodiment, the adaptive array apparatus of the present invention is applied to a path diversity. The path diversity means a method where signals which reach at

different times (the signal which reaches first is referred to as a direct wave and signals following the direct wave are referred to as delayed waves) are separately received and are combined to generate received signals.

5 The simplified construction of the adaptive array apparatus of the present embodiment is almost the same as that of the adaptive array apparatus of Embodiment 1 shown in Fig. 1. Therefore, the following description centers on the different aspect between these adaptive array
10 apparatuses. The different aspect is that the adaptive array apparatus of the present embodiment generates directivity patterns for direct waves and delayed waves of one user, instead of for a plurality of users. The delayed waves mean radio waves that are sent from a user, are
15 reflected by buildings, trains, and automobiles, and reach an adaptive array apparatus following the direct wave. Therefore, the directivity patterns for the delayed waves are different from those for the direct waves. As a result, the adaptive array apparatus of the present embodiment is
20 constructed to generate separate directivity patterns for direct waves and delayed waves. To do so, the adaptive array apparatus of the present embodiment willingly selects and receives delayed waves as well as direct waves, and combines the delayed waves with the direct waves.

25 Fig. 11 is the timing chart of the calculation processing of the control unit 50. This drawing is the same

as Fig. 5 except that the directivity patterns are generated for a direct wave and delayed waves 1-3, instead of for the users "a"-"d".

Therefore, different processing is performed to set
5 the reference signal in step 94 in Fig. 9. The control unit 50 sets an estimated waveform as the reference signal $d(t)$ corresponding to the direct wave in the same way as Embodiment 1. The control unit 50 temporarily determines the symbol of a direct wave to obtain a received signal,
10 gives an estimated delay time to the received signal to obtain an estimated waveform, and sets the estimated waveform as the reference signal $d(t)$ corresponding to each delayed wave.

The received signals of the direct wave and the
15 delayed waves 1-3 are combined using the corresponding weighting factors and are used to judge received symbols.

In this manner, the adaptive array apparatus of the present embodiment willingly selects and receives a plurality of delayed waves as well as direct waves and
20 judges final received symbols using a result where the direct and delayed waves are combined. As a result, C/N ratio is improved, which improves the reliability even if the propagation circumstances of radio waves are deteriorated due to fading.

25 As described above, when signals are processed only by the direct calculation processing, the amount of signal

processing is considerably increased. To cope with this problem, in each embodiment, the indirect calculation processing (the interpolation processing) is also performed at an appropriate ratio. As a result, the amount of signal processing is substantially reduced.

The probability of degradation in characteristics caused by the interpolation processing is described below.

When data is calculated by interpolation, there is ordinarily a probability of degradation in characteristics, in comparison with the case where all data is calculated by the direct calculation processing. This is because there are errors between data calculated by the indirect calculation processing and actual data. Therefore, as the number of pieces of data calculated by the indirect calculation processing is increased, the probability of degradation in characteristics increases.

In each embodiment, however, the changes in weighting factors that are calculated by the interpolation processing are sufficiently reduced. Therefore, the influences of the errors and the probability of degradation in characteristics are reduced. That is, the interval between the interpolation processing where characteristics are not degraded is determined by the changing ratio of weighting factors.

The changes in weighting factors are caused by the changes in the propagation circumstances due to the mobility

of users, and the changing ratio of weighting factors are proportional to the moving speed of the users. Accordingly, the upper limit to the changing ratio of weighting factors can be found from the upper limit to the moving speed of users. As a result, even if the transfer speed is high, the degradation in characteristics is not caused by setting the intervals between interpolation processing no more than the upper limit to the changing ratio of weighting factors.

Therefore, when the intervals between interpolation processing of the adaptive array apparatus of the present invention is no more than the upper limit to the changing ratio of weighting factors, the adaptive array apparatus of the present invention can be basically used without reference to the transfer speed.

It should be noted here that the adaptive array apparatus of the present invention can be modified as described below. Fig. 12 shows modifications of the adaptive array apparatus of the present invention as well as the adaptive array apparatuses of Embodiments 1-3.

In this drawing, four symbol periods are regarded as one cycle and each symbol period in each cycle is cyclically set as time slots 1-4. In this drawing, Case No. 1 concerns Embodiment 1, and Case No. 2 concerns Embodiment 3.

Case No. 3 concerns the case where the direct waves are obtained in the time slots 1 and 3 and the delayed waves are obtained in the time slots 2 and 4 for one user. In

this case, the direct calculation processing is performed in one out of every two symbol periods and the indirect calculation processing is performed in the remaining one symbol period to calculate weighting factors.

5 Case No. 4 concerns the case where the direct wave is obtained in the time slots 1 and 3 for one user. In this case, the weighting factors corresponding to the time slots 1 and 3 are calculated by the direct calculation processing and the weighting factors corresponding to the time slots 2
10 and 4 are calculated by the indirect calculation processing.

 Case No. 5 concerns the case where the direct wave is obtained in the time slot 1 and the delayed wave is obtained in the time slot 3 for one user. In this case, the
15 weighting factor corresponding to one symbol of the direct wave and the weighting factor corresponding to one symbol of the delayed wave are calculated by the direct calculation processing and the weighting factors corresponding to remaining three symbols are calculated by the indirect
20 calculation processing.

 Case No. 6 concerns the case where two users "1" and "2" share an adaptive array apparatus and weighting factors are calculated for the user "1" in the first and third time slots and weighting factors are calculated for the user "2"
25 in the second and fourth time slots. In this case, for each user, weighting factors corresponding to one out of every

two symbols are calculated by the direct calculation processing and weighting factors corresponding to the remaining one symbol are calculated by the indirect calculation processing.

5 Case No. 7 concerns the case where two users "1" and "2" share an adaptive array apparatus and the weighting factors corresponding to the direct wave of the user "1" is calculated in the first time slot, the weighting factors corresponding to the delayed wave of the user "1" is
10 calculated in the second time slot, the weighting factors corresponding to the direct wave of the user "2" is calculated in the third time slot, and the weighting factors corresponding to the delayed wave of the user "2" is
15 calculated in the fourth time slot. In this case, for each of the direct and delayed waves of each user, weighting factors corresponding to one out of four symbols are calculated by the direct calculation processing and weighting factors corresponding to the remaining three symbols are calculated by the indirect calculation
20 processing.

Weighting factors are also appropriately calculated in Case Nos. 8, 9, and 10 in the manner shown in Fig. 12.

In each embodiment, as shown in Figs. 5, 10, and 11, the control unit 50 calculates weighting factors
25 corresponding to direct waves or delayed waves for a specific user in allocated symbol periods. However, the

calculation of weighting factors does not necessarily synchronize to symbol periods. That is, as each embodiment, the adaptive array apparatus of the present invention may operate in synchronization with receiving times of symbols (I and Q components) in real time. The adaptive array apparatus may also store symbols received in a predetermined number of symbol periods and process the stored symbols by one operation.

10 INDUSTRIAL USE POSSIBILITY

As described above, the adaptive array apparatus of the present invention is very useful as a base station for mobile communication.

CLAIMS

3 1. An adaptive array apparatus, including a plurality of
4 pairs of an antenna and a radio unit, for transmitting and
5 receiving symbols using the radio units in each symbol
6 period using combining coefficients, the combining
7 coefficients being calculated for each radio unit and being
8 used for forming a directivity pattern, the adaptive array
9 apparatus comprising:

10 a storing means for storing symbols that are received
11 by every radio unit in a plurality of symbol periods, each
12 radio unit receiving a symbol in each symbol period;

13 a calculation means for calculating combining
14 coefficients corresponding to a given symbol period out of
15 the plurality of symbol periods, based on symbols
16 corresponding to the given symbol period out of the stored
17 symbols; and

18 an interpolation means for interpolating combining
19 coefficients corresponding to symbol periods other than the
20 given symbol period out of the plurality of symbol periods,
21 based on the calculated combining coefficients.

1 2. The adaptive array apparatus of Claim 1,
2 wherein the storing means stores symbols that are
3 received in the latest k symbol periods (k is no less than
4 two),





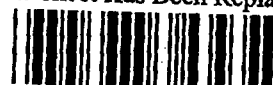
5 the calculation means calculates combining
6 coefficients corresponding to a given symbol period out of
7 every group of k symbol periods, there being $k-1$ symbol
8 periods between the given symbol period and a previous given
9 symbol period for which the calculation means calculated
10 combining coefficients, and

11 the interpolation means interpolates combining
12 coefficients corresponding to the $k-1$ symbol periods between
13 the given symbol period and the previous given symbol
14 period, based on the combining coefficients calculated for
15 the given symbol period and the previous given symbol
16 period.

1 3. The adaptive array apparatus of Claim 2,
2 wherein the interpolation means linearly interpolates
3 the combining coefficients corresponding to the $k-1$ symbol
4 periods based on the combining coefficients calculated for
5 the given symbol period and the previous given symbol
6 period.

1 4. The adaptive array apparatus of Claim 2,
2 wherein the interpolation means uses the combining
3 coefficients corresponding to the previous given symbol
4 period as the interpolated combining coefficients.

1 5. The adaptive array apparatus of Claim 2,





2 wherein the interpolation means uses the combining
3 coefficients corresponding to the given symbol period as the
4 interpolated combining coefficients.

1 6. The adaptive array apparatus of Claim 2,
2 wherein the calculation means calculates combining
3 coefficients used for forming a directivity pattern for one
4 user radio in the given symbol period and calculates
5 combining coefficients used for forming a directivity
6 pattern for another user radio in a different given symbol
7 period out of every group of k symbol periods, there being
8 $k-1$ symbol periods between the different given symbol period
9 and a previous different given symbol period for which the
10 calculation means calculates combining coefficients used for
11 forming the directivity pattern for the other user radio,
12 and

13 the interpolation means interpolates combining
14 coefficients corresponding to the $k-1$ symbol periods between
15 the given symbol period and the previous given symbol
16 period, based on the combining coefficients calculated in
17 the given symbol period and the previous given symbol
18 period, and interpolates combining coefficients
19 corresponding to the $k-1$ symbol periods between the
20 different given symbol period and the previous different
21 given symbol period, based on the combining coefficients
22 calculated in the different given symbol period and the





23 previous different given symbol period.

1 7. The adaptive array apparatus of Claim 6,
2 wherein each symbol is expressed by an inphase
3 component and a quadrature component,
4 the storing means stores inphase components and
5 quadrature components of the symbols received in the latest
6 k symbol periods,
7 the calculation means calculates combining
8 coefficients corresponding to inphase components and
9 quadrature components of the symbols corresponding to the
10 given symbol period out of the stored symbols, based on the
11 inphase components and the quadrature components of the
12 corresponding symbols, and
13 the interpolation means interpolates combining
14 coefficients corresponding to the k-1 symbol periods between
15 the given symbol period and the different given symbol
16 period, based on the combining coefficients calculated in
17 the given symbol period and the different given symbol
18 period.

1 8. The adaptive array apparatus of Claim 2,
2 wherein the calculation means calculates combining
3 coefficients used for forming a directivity pattern for a
4 direct wave in the given symbol period and calculates
5 combining coefficients used for forming a directivity

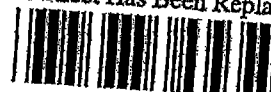




6 pattern for an indirect wave in a different given symbol
7 period out of every group of k symbol periods, there being
8 $k-1$ symbol periods between the different given symbol period
9 and a previous different given symbol period for which the
10 calculation means calculated combining coefficients used for
11 forming the directivity pattern for the indirect wave, and
12 the interpolation means interpolates the combining
13 coefficients corresponding to the $k-1$ symbol periods between
14 the given symbol period and the different given symbol
15 period, based on the combining coefficients calculated in
16 the given symbol period and the previous given symbol
17 period, and interpolates combining coefficients
18 corresponding to $k-1$ symbol periods between the different
19 given symbol period and the previous different given symbol
20 period, based on the combining coefficients calculated in
21 the different given symbol period and the previous different
22 given symbol period.

1 9. The adaptive array apparatus of one of Claims 1-7,
2 wherein the calculation means and the interpolation
3 means include a programmable digital signal processor.

1 10. An adaptive array apparatus, including a plurality of
2 pairs of an antenna and a radio unit, for transmitting and
3 receiving symbols using the radio units in each symbol
4 period using combining coefficients, the combining





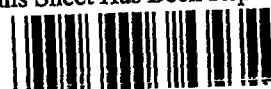
5 coefficients being calculated for each radio unit and being
6 used for forming directivity patterns which each correspond
7 to one of a plurality of user radios, the adaptive array
8 apparatus comprising:

9 a storing means for storing symbols that are received
10 by every radio unit in the latest k symbol periods (k is no
11 less than three), each radio unit receiving a symbol in each
12 symbol period;

13 a calculation means for calculating combining
14 coefficients corresponding to a given symbol period out of
15 every group of k symbol periods, based on symbols
16 corresponding to the given symbol period out of the stored
17 symbols, there being $k-1$ symbol periods between the given
18 symbol period and a previous given symbol period for which
19 the calculation means calculated combining coefficients;
20 and

21 an interpolation means for interpolating combining
22 coefficients corresponding to the $k-1$ symbol periods between
23 the given symbol period and the previous given symbol
24 period, based on the calculated combining coefficients
25 corresponding to the given symbol period and the previous
26 given symbol period.

- 1 11. The adaptive array apparatus of Claim 10,
2 wherein k is no less than a number of symbol periods
3 that equates to the time taken by the calculation means to



WO 00/60764



PCT/JP99/01828

- 4 calculate combining coefficients for all of the plurality of
- 5 user radios.

This Sheet Has Been Replaced

