(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
19 January 2017 (19.01.2017)

WIPO | PCT

(10) **International Publication Number**
WO 2017/008307 A1

(51) **International Patent Classification**:
H04B 7/04 (2006.01)

(21) **International Application Number**:
PCT/CN2015/084246

(22) **International Filing Date**:
16 July 2015 (16.07.2015)

(25) **Filing Language**: English

(26) **Publication Language**: English

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) **Title**: METHOD AND APPARATUS FOR PERFORMING BEAMFORMING

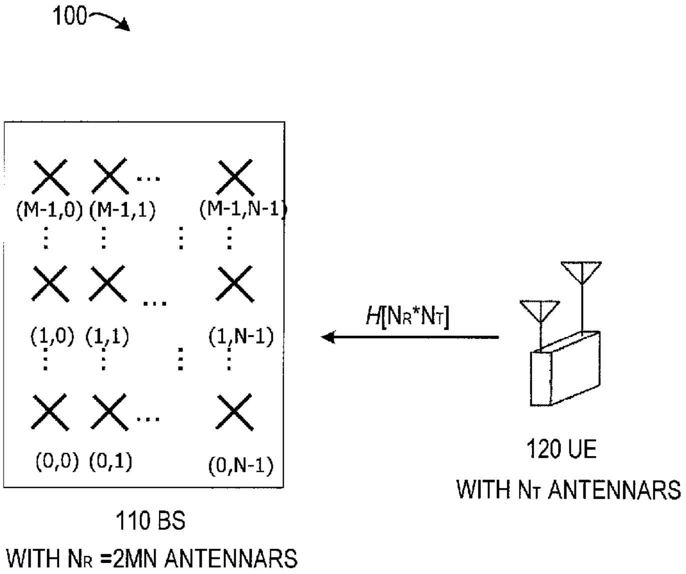

FIG. 1

(57) **Abstract**: Embodiments of the disclosure provide a method and apparatus for performing beamforming in a MIMO system. The method may comprise : obtaining an initial channel matrix based on reference signals received via the first and second antenna arrays from a UE, wherein the initial channel matrix includes channel parameters associated with both the first antenna array and the second antenna array; determining vertical beamforming vectors and horizontal beamforming vectors based on the initial channel matrix; determining a first 3D beamforming vector and a second 3D beamforming vector based on the vertical beamforming vectors and the horizontal beamforming vectors, wherein the first 3D beamforming vector is associated with the polarization of the first antenna array, and the second 3D beamforming vector is associated with the polarization of the second antenna array; determining, at least in part based on the initial channel matrix, a phase factor matrix for polarizations of the first antenna array and the second antenna array; and determining a beamforming parameter matrix based on the phase factor matrix, the first 3Dbeamforming vector and the second 3D beamforming vector.

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METHOD AND APPARATUS FOR PERFORMING BEAMFORMING

FIELD OF THE INVENTION

[0001] Embodiments of the present invention generally relate to communication techniques. More particularly, embodiments of the present invention relate to a method and apparatus for performing beamforming.

BACKGROUND OF THE INVENTION

[0002] Multiple Input Multiple Output (MIMO) is a key feature of Long Term Evolution (LTE)/LTE-Advanced (LTE-A) system. Conventionally, one-dimensional (horizontal) antenna array provides flexible beamforming adaption in the azimuth domain. It has been recently found that the full MIMO capability can be exploited through leveraging a two dimensional antenna system (AAS), such that it is possible to implement user-specific elevation beamforming and spatial multiplexing in the vertical domain.

[0003] Conventionally, for performing beamforming in the MIMO system, eigenvector(s) obtained by eigenvalue decomposition have been used as beamforming weight(s) or precoder(s) in transmission/reception of a signal, in order to improve radio characteristics. However, due to the large number of antenna elements in the AAS, complexity of conventional decomposition of channel covariance matrix is extremely high.

[0004] Therefore, there is a need for reducing complexity in determination of the precoder.

SUMMARY OF THE INVENTION

[0005] The present invention proposes a solution for performing beamforming with low complexity in determination of the precoder, while obtaining an average gain which can get high tolerance of uplink channel estimation.

[0006] According to a first aspect of embodiments of the present invention, embodiments of the invention provide a method of performing beamforming in a MIMO system, wherein a base station (BS) in the MIMO system includes a first antenna array and a second antenna array, each of the first antenna array and the second antenna array contains a plurality of antennas, and the first antenna array and the second antenna array have the same size and are cross-polarized. The method comprises: obtaining an initial channel matrix based on reference signals received via the first and second antenna arrays from user equipment (UE), wherein the initial channel matrix includes channel parameters associated with both the first antenna array and the second antenna array; determining vertical beamforming vectors and horizontal beamforming vectors based on the initial channel matrix; determining a first three-dimensional (3D) beamforming vector and a second 3D beamforming vector based on the vertical beamforming vectors and the horizontal beamforming vectors, wherein the first 3D beamforming vector is associated with the polarization of the first antenna array, and the second 3D beamforming vector is associated with the polarization of the second antenna array; determining, at least in part based on the initial channel matrix, a phase factor matrix for polarizations of the first antenna array and the second antenna array; and determining a beamforming parameter matrix based on the phase factor matrix, the first 3Dbeamforming vector and the second 3D beamforming vector.

[0007] According to a second aspect of embodiments of the present invention, embodiments of the invention provide an apparatus for performing beamforming in a MIMO system, wherein a BS in the MIMO system includes a first antenna array and a second antenna array, each of the first antenna array and the second antenna array contains a plurality of antennas, and the first antenna array and the second antenna array have the same size and are cross-polarized. The apparatus comprises: an obtaining unit configured to obtain an initial channel matrix based on reference signals received via the first and second antenna arrays from a UE, wherein the initial channel matrix includes channel parameters associated with both the first antenna array and the second antenna array; a first determining unit configured to determine vertical beamforming vectors and horizontal beamforming vectors based on the initial channel matrix; a second determining unit configured to determine a first 3D beamforming vector and a second 3D beamforming vector based on the vertical beamforming vectors and the horizontal beamforming vectors, wherein the first 3D beamforming vector is associated with the polarization of the first antenna array, and the second 3D beamforming vector is associated with the polarization of the second antenna array; a third determining unit configured to determine, at least in part based on the initial channel matrix, a phase factor matrix for polarizations of the first antenna array and the second antenna array; and a fourth determining unit configured to determine a beamforming parameter matrix based on the phase factor matrix, the first 3Dbeamforming vector and the second 3D beamforming vector.

[0008] Other features and advantages of the embodiments of the present invention will also be apparent from the following description of specific embodiments when read in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Embodiments of the invention are presented in the sense of examples and their advantages are explained in greater detail below, with reference to the accompanying drawings, where

[0010] FIG. 1 illustrates a schematic diagram of a MIMO system according to embodiments of the invention;

[0011] FIG. 2 illustrates a flow chart of a method for performing beamforming in a MIMO system according to embodiments of the invention;

[0012] FIG. 3 illustrates a flow chart of a method for determining vertical beamforming vectors and horizontal beamforming vectors according to embodiments of the invention;

[0013] FIG. 4 illustrates a flow chart of a method for determining vertical beamforming vectors and horizontal beamforming vectors according to further embodiments of the invention;

[0014] FIG. 5 illustrates a flow chart of a method for determining vertical beamforming vectors and horizontal beamforming vectors according to embodiments of the invention;

[0015] FIG. 6 illustrates a flow chart of a method for determining vertical beamforming vectors and horizontal beamforming vectors according to further embodiments of the invention;

[0016] FIG. 7 illustrates a flow chart of a method for determining a phase factor matrix according to embodiments of the invention;

[0017] FIG. 8 illustrates a flow chart of a method for determining a phase factor matrix according to further embodiments of the invention;

[0018] FIG. 9 illustrates a schematic diagram of an apparatus for performing beamforming in a MIMO system according to embodiments of the invention;

[0019] FIG. 10A illustrates a diagram of dividing the initial channel matrix into 2N groups according to embodiments of the present invention;

[0020] FIG. 10B illustrates a diagram of determination of the vertical beamforming vectors according to embodiments of the present invention;

[0021] FIG. 11 illustrates a diagram of obtaining the horizontal composition channel matrix according to embodiments of the present invention;

[0022] FIG. 12 illustrates a diagram of determination of the first and second horizontal beamforming vectors and the first and second 3D beamforming vectors according to embodiments of the present invention;

[0023] FIG. 13 illustrates a diagram of determination of the vertical beamforming vectors according to embodiments of the present invention;

[0024] FIG. 14 illustrates a diagram of determination of the vertical beamforming vectors according to embodiments of the present invention;

[0025] FIG. 15 illustrates a diagram of dividing of the initial channel matrix according to embodiments of the present invention;

[0026] FIG. 16 illustrates a diagram of obtaining the horizontal beamforming vectors according to embodiments of the present invention;

[0027] FIG. 17 illustrates a diagram of determination of the horizontal beamforming vectors according to embodiments of the present invention;

[0028] FIG. 18 illustrates a diagram of determination of the horizontal beamforming vectors according to embodiments of the present invention;

[0029] FIG. 19 illustrates a diagram of obtaining the composition channel matrix according to embodiments of the present invention;

[0030] FIG. 20 illustrates a diagram of a process for determining the phase factor matrix and the beamforming parameter matrix according to embodiments of the present invention; and

[0031] FIG. 21 illustrates a diagram of a process for determining the phase factor matrix and the beamforming parameter matrix according to embodiments of the present invention.

[0032] Throughout the figures, same or similar reference numbers indicate same or similar elements.

DETAILED DESCRIPTION OF EMBODIMENTS

[0033] The subject matter described herein will now be discussed with reference to several example embodiments. It should be understood these embodiments are discussed only for the purpose of enabling those skilled persons in the art to better understand and thus implement the subject matter described herein, rather than suggesting any limitations on the scope of the subject matter.

[0034] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of example embodiments. As used herein, the singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises,” “comprising,” “includes” and/or “including,” when used herein, specify the presence of stated features, integers, steps, operations, elements and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components and/or groups thereof.

[0035] It should also be noted that in some alternative implementations, the functions/acts noted may occur out of the order noted in the figures. For example, two functions or acts shown in succession may in fact be executed concurrently or may sometimes be executed in the reverse order, depending upon the functionality/acts involved.

[0036] As used herein, the term “base station” or “BS” represents a node B (NodeB or NB), an evolved NodeB (eNodeB or eNB), a Remote Radio Unit (RRU), a radio header (RH), a remote radio head (RRH), a relay, a low power node such as a femto, a pico, and so forth.

[0037] As used herein, the term "user equipment" or "UE" refers to any device that is capable of communicating with the BS. By way of example, the UE may include a terminal, a Mobile Terminal (MT), a Subscriber Station (SS), a Portable Subscriber Station, a Mobile Station (MS), or an Access Terminal (AT).

[0038] Embodiments of the present invention may be applied in various communication systems, including but not limited to a Long Term Evolution (LTE) system or a Long Term Evolution Advanced (LTE-A) system. Given the rapid development in communications, there will of course also be future type wireless communication technologies and systems with which the present invention may be embodied. It should not be seen as limiting the scope of the invention to only the aforementioned system.

[0039] Now some exemplary embodiments of the present invention will be described below with reference to the figures. Reference is first made to FIG. 1, which illustrates a schematic diagram of a MIMO system 100 according to embodiments of the invention.

[0040] In the MIMO system 100, a BS 110 and a UE 120 are exemplarily illustrated. The BS includes a first antenna array and a second antenna array, each of them containing a plurality of antennas. The first antenna array and the second antenna array are cross-polarized and have the same size. In the embodiments of FIG. 1, either the first antenna array or the second antenna array has M antennas in the vertical direction and N antennas in the horizontal direction, wherein each of M and N is a natural number. In other words, the first antenna array includes $M \times N$ antennas, and the second antenna array includes $M \times N$ antennas as well. As such, for the BS 110, there are N_R=2MN antennas in total. With respect to the UE 120, there are N_T antennas for communication with the BS 110. In this case, information about a channel from the UE 120 to the BS 110 may be indicated by $H[N_R \times N_T]$.

[0041] In the embodiments of FIG. 1, the UE 120 exemplarily comprises two antennas. That is, N_T=2. It is to be noted that, the example shown with respect to FIG. 1 is for purpose of illustration, rather than limitation. Those skilled in the art will appreciate that any suitable number of antennas may be employed in communication between the BS 110 and the UE 120.

[0042] Conventionally, in the determination of a beamforming parameter matrix (sometimes called as "precoder" or "beamforming parameters") for performing beamforming, one or more channel covariance matrices need to be decomposed. Since the decomposition complexity with respect to a large-size antenna array is extremely high, embodiments of the present invention propose a solution to solve this problem. In this way, the beamforming parameter matrix may be determined with reduced complexity.

[0043] Reference is now made to FIG. 2, which illustrates a flow chart of a method 200 for performing beamforming in a MIMO system according to embodiments of the invention. In embodiments with respect to FIG. 2, the MIMO system may be implemented as the MIMO system 100 shown in FIG. 1. However, it is noted that this is only for the purpose of illustrating the principles of the present invention, rather than limiting the scope thereof. The method 200 may be implemented in any other suitable MIMO system within the scope of the subject matter.

[0044] The method 200 starts in step 210, in which an initial channel matrix is obtained based on reference signals received via the first and second antenna arrays from a UE, wherein the initial channel matrix includes channel parameters associated with both the first antenna array and the second antenna array.

[0045] According to embodiments of the present invention, the initial channel matrix may represent channel information characterizing the channel from the UE 120 to the BS 110, and may include channel parameters associated with both the first antenna array and the second antenna array. As discussed with respect to embodiments of FIG. 1, the initial channel matrix may be denoted as $H[N_R \times N_T]$.

[0046] It is to be noted that although the initial channel matrix is illustrated in the form of a matrix, but it is just an example rather than limitation. Those skilled in the art will appreciate that the initial channel matrix may have some other suitable forms. For example, the initial channel matrix may be a set including multiple groups (for example M groups) of channel parameters, and each group comprises a certain number of channel parameters (for example, N channel parameters).

[0047] According to embodiments of the present invention, the initial channel matrix may be obtained in several ways. In one embodiment, the UE may send reference signals such as sounding reference signals (SRSs) to the BS. The BS may measure the reference signals and determine the initial channel matrix based thereon. It is to be noted that this embodiment is illustrated for purpose of example, rather than limitation. Those skilled in the art can obtain the initial channel matrix by means of some other conventional techniques, and relevant descriptions are not detailed here.

[0048] In step 220, vertical beamforming vectors and horizontal beamforming vectors are determined based on the initial channel matrix.

[0049] According to embodiments of the present invention, the vertical beamforming vectors and horizontal beamforming vectors may be determined in several ways. In some embodiments, the vertical beamforming vectors may be calculated based on the initial channel matrix. Then, a first horizontal beamforming vector and a second horizontal beamforming vector may be calculated based on the vertical beamforming vectors as well as the initial channel matrix. Details of these embodiments will be described with respect to FIG. 3.

[0050] Alternatively, in some embodiments, the vertical beamforming vectors may be calculated based on the initial channel matrix. The horizontal beamforming vectors may be calculated based on the initial channel matrix. In other words, the horizontal beamforming vectors may be calculated independent of the vertical beamforming vectors. Thus, the calculation of the vertical beamforming vectors may occur either before or after the calculation of the horizontal beamforming vectors, or both of the calculations be executed concurrently. Details of these embodiments will be described with respect to FIG. 5.

[0051] In step 230, a first three-dimensional (3D) beamforming vector and a second 3D beamforming vector are determined based on the vertical beamforming vectors and the horizontal beamforming vectors, wherein the first 3D beamforming vector is associated with the polarization of the first antenna array, and the second 3D beamforming vector is associated with the polarization of the second antenna array.

[0052] According to embodiments of the present invention, the first 3D beamforming vector and the second 3D beamforming vector may be determined in several ways. In some embodiments, the vertical beamforming vectors may be divided into two parts, wherein the first part of the vertical beamforming vectors may be associated with the polarization of the first antenna array, and the second part of the vertical beamforming vectors may be associated with the polarization of the second antenna array. As such, in these embodiments where a first horizontal beamforming vector and a second horizontal beamforming vector are calculated based on the vertical beamforming vectors and the initial channel matrix, the first 3D beamforming vector may be calculated based on a first part of the vertical beamforming vectors and the first horizontal beamforming vector, and the second 3D beamforming vector may be calculated based on a second part of the vertical beamforming vectors and the second horizontal beamforming vector. It is to be noted that the calculation of the first 3D beamforming vector and the calculation of the second 3D beamforming vector may execute in sequence, concurrently or in the reverse order.

[0053] Alternatively, in some embodiments where the horizontal beamforming vectors are calculated independent of the vertical beamforming vectors, the first 3D beamforming vector may be calculated based on a first part of the vertical beamforming vectors and a first part of the horizontal beamforming vectors, and the second 3D beamforming vector may be calculated based on a second part of the vertical beamforming vectors and a second part of the horizontal beamforming vectors. In such embodiments, the first part of the vertical beamforming vectors and the first part of the horizontal beamforming vectors may be associated with the polarization of the first antenna array respectively, and the second part of the vertical beamforming vectors and the second part of the horizontal beamforming vectors may be associated with the polarization of the second antenna array respectively.

[0054] In step 240, a phase factor matrix for polarizations of the first antenna array and the second antenna array is determined at least in part based on the initial channel matrix.

[0055] The phase factor matrix is associated with the different polarizations of the first antenna array and the second antenna array. According to embodiments of the present invention, the phase factor matrix may be determined in multiple ways. In some embodiments, the initial channel matrix may be divided into a first channel matrix and a second channel matrix, wherein the first channel matrix is associated with the first antenna array and the second channel matrix is associated with the second antenna array.

A composition channel matrix then may be obtained based on the first 3D beamforming vector, the second 3D beamforming vector, the first channel matrix and the second channel matrix. Next, a composition covariance matrix of the composition channel matrix may be calculated and then averaged in a third predetermined period of time or a third predetermined frequency band. Then, the phase factor matrix may be determined by performing decomposition (for example EVD) based on the averaging results. Details of the embodiments will be described with respect to FIG. 7.

[0056] Alternatively, in some embodiments, the phase factor matrix may be directly determined from the initial channel matrix, without using the first 3D beamforming vector or the second 3D beamforming vector. More specifically, a simplified channel matrix may be determined from the initial channel matrix. The simplified channel matrix may include channel parameters associated with a pair of antennas that have different polarizations, wherein one of the pair of antennas belongs to the first antenna array and the other of the pair of antennas belongs to the second antenna array. Next, a simplified covariance matrix of the simplified channel matrix may be calculated and averaged in a third predetermined period of time or a third predetermined frequency band. Then, the phase factor matrix may be determined by performing decomposition based on the averaging results. Details of the embodiments will be described with respect to FIG. 8.

[0057] In step 250, a beamforming parameter matrix is determined based on the phase factor matrix, the first 3D beamforming vector and the second 3D beamforming vector.

[0058] In some embodiments, the beamforming parameter matrix may be obtained by applying the phase factor matrix to the first 3D beamforming vector and the second 3D beamforming vector. By way of example, assuming that the first 3D beamforming vector and the second 3D beamforming vector obtained in step 230 are denoted as V_A^{3D} and V_B^{3D} respectively, and the phase factor matrix obtained in step 240 is denoted as

$$V_p = \begin{bmatrix} V_p(0,0) & V_p(0,1) \\ V_p(1,0) & V_p(1,1) \end{bmatrix}. \tag{1}$$

[0059] The beamforming parameter matrix V_F may be determined based on the phase factor matrix, the first 3D beamforming vector and the second 3D beamforming vector as follows:

$$V_F = \begin{bmatrix} V_F(0,0)\cdot V_A^{3D} & V_F(0,1)\cdot V_A^{3D} \\ V_F(1,0)\cdot V_B^{3D} & V_F(1,1)\cdot V_B^{3D} \end{bmatrix}. \qquad (2)$$

[0060] In this way, the complexity of determining the beamforming parameter matrix can be reduced, and the beamforming parameter matrix can be obtained in a fast and efficient manner.

[0061] Reference is now made to FIG. 3, which illustrates a flow chart of a method 300 for determining vertical beamforming vectors and horizontal beamforming vectors according to embodiments of the invention. The method 300 may be considered as a specific implementation of step 220 of method 200 described above with reference to Fig. 2. However, it is noted that this is only for the purpose of illustrating the principles of the present invention, rather than limiting the scope thereof.

[0062] In step 310, the vertical beamforming vectors are calculated based on the initial channel matrix.

[0063] According to embodiments of the present invention, the vertical beamforming vectors may be obtained in several ways. In some embodiments, elements of the initial channel matrix may be divided into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array. Next, 2N vertical covariance matrices of the 2N groups may be calculated respectively, and averaged in a first predetermined period of time or a first predetermined frequency band respectively. Then, 2N eigenvectors may be calculated based on the averaging results as the vertical beamforming vectors.

[0064] Alternatively, in some embodiments, the calculation of the 2N eigenvectors as discussed above may be simplified as calculating one eigenvector. More specifically, elements of the initial channel matrix may be divided into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array. Next, 2N vertical covariance matrices of the 2N groups may be calculated. Each of the 2N vertical covariance matrices may be then averaged in a first predetermined period of time or a first predetermined frequency band. Next, a sum or a mean value of the averaging results may be calculated. Then, an eigenvector which is calculated based on the sum or the mean value may be determined as ach of the vertical beamforming vectors. In this way, all of the vertical beamforming vectors are identical.

[0065] As a further alternative, in some embodiments, elements of the initial channel matrix may be divided into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array. Next, a vertical covariance matrix of one of the 2N groups may be calculated and averaged in a first predetermined period of time or a first predetermined frequency band. Then, an eigenvector calculated based on the averaging result may be determined as each of the vertical beamforming vectors.

[0066] In step 320, a first horizontal beamforming vector and a second horizontal beamforming vector are calculated based on the initial channel matrix and the vertical beamforming vectors.

[0067] To better understand steps 310 and 320, reference is made to FIG. 4, which illustrates a flow chart of a method 400 for determining vertical beamforming vectors and horizontal beamforming vectors according to further embodiments of the invention. The method 400 may be considered as a specific implementation of method 300 described above with reference to Fig. 3. More specifically, steps 410-440 corresponds to an implementation of step 310, and steps 450-490 corresponds to an implementation of step 320. However, it is noted that this is only for the purpose of illustrating the principles of the present invention, rather than limiting the scope thereof.

[0068] In step 410, elements of the initial channel matrix are divided into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array.

[0069] According to embodiments of the present invention, the method 400 may be applicable in the MIMO system 100. As discussed with respect to embodiments of FIG. 1, the initial channel matrix obtained in the MIMO system 100 is $H[N_R \times N_T]$. Since N_R=2MN, the initial channel matrix may be expressed as $H[2MN \times N_T]$. In step 410, the initial channel matrix $H[2MN \times N_T]$ may be divided into 2N groups, that is H_0, ..., H_{N-1} and H_N, ..., H_{2N-1}, wherein each of H_0, ..., H_{N-1} and H_N, ..., H_{2N-1} is a

$M \times N_T$ matrix. FIG. 10A illustrates a diagram of dividing the initial channel matrix into 2N groups according to embodiments of the present invention.

[0070] In step 420, 2N vertical covariance matrices of the 2N groups are calculated.

[0071] For each of the 2N groups H_0, ..., H_{N-1} and H_N, ..., H_{2N-1}, such as H_i (i=0, 1, ..., N-1, N,..., 2N-1), a corresponding vertical covariance matrix, R_i, may be calculated as follows:

$$R_i = H_i \cdot H_i^H \tag{3}$$

where H_i^H represents conjugation of H_i.

[0072] In step 430, each of the 2N vertical covariance matrices is averaged in a first predetermined period of time or a first predetermined frequency band.

[0073] In this step, each of the 2N vertical covariance matrices, R_i, may be averaged in a first predetermined period of time or a first predetermined frequency band. The first predetermined period of time or the first predetermined frequency band may be referred to as the first range and may be preset according to system conditions, certain requirements or the like. In some embodiments, the R_i may be averaged on a certain number of resource blocks (RBs). The averaged R_i may be denoted as $\overline{R}_i$. In this way, $\overline{R}_0$, ..., $\overline{R}_{2N-1}$ can be obtained.

[0074] In step 440, 2N eigenvectors calculated based on the averaging results are determined as the vertical beamforming vectors.

[0075] With respect to each of the averaged vertical covariance matrices, a decomposition operation, such as $M \times M$ Eigen Value Decomposition (EVD), may be carried out, and an eigenvector may be obtained therefrom. By way of example, an eigenvector V_i may be calculated from the following:

$$\overline{R}_i = V_i D_i^2 V_i^H \tag{4}$$

where D_i is an eigenvalue matrix; and V_i is the eigenvector corresponding to the maximum eigenvalue.

[0076] Accordingly, 2N eigenvectors V_0, V_1,... V_{2N-1} may be calculated from equation (4) and may be determined as 2N vertical beamforming vectors. The size of each of the

2N vertical beamforming vectors $V_0, V_1, \ldots V_{2N-1}$ is $M \times 1$.

[0077] FIG. 10B illustrates a diagram 1000 of determination of the vertical beamforming vectors according to embodiments of the present invention. As can be seen from FIG. 10B, 2N vertical beamforming vectors $V_0[M \times 1]$, $V_1[M \times 1], \ldots V_{2N-1}[M \times 1]$ are obtained from the initial channel matrix $H[N_R \times N_T]$ after calculating covariance matrices, averaging, and performing EVD.

[0078] Still in reference to FIG. 4, in step 450, a horizontal composition channel matrix is obtained based on the initial channel matrix and the vertical beamforming vectors.

[0079] In some embodiments, the horizontal composition channel matrix may be obtained by applying the 2N vertical beamforming vectors $V_0, V_1, \ldots V_{2N-1}$ to conjugation of $H_0, \ldots, H_{N-1}$ and $H_N, \ldots, H_{2N-1}$, respectively. More specifically, the horizontal composition channel matrix (denoted as $\tilde{H}$) may be obtained as follows:

$$\tilde{H}[N_T \times 2N] = [\tilde{H}_0 \quad \cdots \quad \tilde{H}_{N-1} \quad \tilde{H}_N \quad \cdots \quad \tilde{H}_{2N-1}] \tag{5}$$

In equation (5), $\tilde{H}_i$ (i=0, ..., N-1, N, ..., 2N-1) can be calculated by:

$$\tilde{H}_i[N_T \times 1] = H_i^H \cdot V_i, \tag{6}$$

in which H_i^H is conjugation of H_i, and V_i is the ith vertical beamforming vector, i=0, ..., N-1, N, ..., 2N-1. The size of H_i^H is $N_T \times M$, and the size of $\tilde{H}_i$ is $N_T \times 1$.

[0080] To better understand the process of step 450, reference is now made to FIG. 11, in which a diagram 1100 of obtaining the horizontal composition channel matrix is illustrated. As shown in FIG. 11, the horizontal composition channel matrix comprises 2N sub-matrices $\tilde{H}_0 \ldots \tilde{H}_{N-1}\tilde{H}_N \ldots \tilde{H}_{2N-1}$, and each of them is calculated by equation (6).

[0081] Still in reference to FIG. 4, in step 460, the horizontal composition channel matrix is divided into a first horizontal channel matrix and a second horizontal channel matrix, wherein the first horizontal channel matrix is associated with the first antenna array and the second horizontal channel matrix is associated with the second antenna array.

[0082] As shown in the embodiments of FIG. 11, the horizontal composition channel matrix $\tilde{H}[N_T \times 2N]$ may be divided into the first horizontal channel matrix $\tilde{H}_A[N_T \times N]$ (sometimes referred to as $\tilde{H}_A$) and the second horizontal channel matrix $\tilde{H}_B[N_T \times N]$ (sometimes referred to as $\tilde{H}_B$). In the embodiments, the first horizontal channel matrix $\tilde{H}_A[N_T \times N]$ includes a half of the 2N sub-matrices, namely, $\tilde{H}_0 \ldots \tilde{H}_{N-1}$, which are associated with the first antenna array. The second horizontal channel matrix $\tilde{H}_B[N_T \times N]$ includes the remaining of the 2N sub-matrices, namely $\tilde{H}_N \ldots \tilde{H}_{2N-1}$, which are associated with the second antenna array.

[0083] In step 470, a first horizontal covariance matrix of the first horizontal channel matrix and a second horizontal covariance matrix of the second horizontal channel matrix are calculated.

[0084] For the first horizontal channel matrix $\tilde{H}_A$, the corresponding covariance matrix, R_A, may be calculated as follows:

$$R_A = \tilde{H}_A^H \cdot \tilde{H}_A. \tag{7}$$

[0085] Likewise, for the second horizontal channel matrix $\tilde{H}_B$, the corresponding covariance matrix, R_B, may be calculated as follows:

$$R_B = \tilde{H}_B^H \cdot \tilde{H}_B. \tag{8}$$

[0086] Thus, the first horizontal covariance matrix R_A and the second horizontal covariance matrix R_B may be obtained based on equations (7) and (8).

[0087] In step 480, each of the first horizontal covariance matrix and the second horizontal covariance matrix is averaged in a second predetermined period of time or a second predetermined frequency band.

[0088] According to embodiments of the present invention, the second predetermined period of time or the second predetermined frequency band may be referred to as the second range and may be preset according to system conditions, certain requirements or the like. In some embodiments, the first horizontal covariance matrix R_A and the second horizontal covariance matrix R_B may be averaged on a certain number of RBs.

The first and second horizontal covariance matrices may be denoted as $\overline{R}_A$ and $\overline{R}_B$.

[0089] According to embodiments of the present invention, the first range may be larger than or equal to the second range. By way of example, the first predetermined period of time may be larger than or equal to the second predetermined period of time, and the first predetermined frequency band may be larger than or equal to the second predetermined frequency band.

[0090] In step 490, an eigenvector calculated based on the averaging of the first horizontal covariance matrix is determined as the first horizontal beamforming vector, and another eigenvector calculated based on the averaging of the second horizontal covariance matrix is determined as the second horizontal beamforming vector.

[0091] In some embodiments, the first and horizontal beamforming vectors may be obtained by performing EVD on $\overline{R}_A$ and $\overline{R}_B$ respectively. By way of example, an eigenvector V_A may be calculated from:

$$\overline{R}_A = V_A D_A^2 V_A^H \tag{9}$$

and may be determined as the first horizontal beamforming vector.

[0092] Likewise, another eigenvector V_B may be calculated from:

$$\overline{R}_B = V_B D_B^2 V_B^H \tag{10}$$

and may be determined as the second horizontal beamforming vector. In the embodiments, the size of V_A is $N \times 1$, and the size of V_B is $N \times 1$.

[0093] According to embodiments of the present invention, with the first horizontal beamforming vector and the second horizontal beamforming vector, the first and second 3D beamforming vectors may be calculated accordingly. In some embodiments, the vertical beamforming vectors obtained at step 440 may be divided into two parts, wherein the first part is associated with the polarization of the first antenna array, and the second part is associated with the polarization of the second antenna array. Then, the first 3D beamforming vector may be calculated based on the first part of the vertical beamforming vectors and the first horizontal beamforming vector. The second 3D beamforming vector may be calculated based on the second part of the vertical beamforming vectors and the second horizontal beamforming vector.

[0094] By way of example, the first 3D beamforming vector (denoted as V_A^{3D}) may be obtained by:

$$V_A^{3D}[MN \times 1] = \begin{bmatrix} V_A(0) \cdot V_0 \\ \vdots \\ V_A(N-1) \cdot V_{N-1} \end{bmatrix} \tag{11}$$

where $V_A = \begin{bmatrix} V_A(0) \\ \vdots \\ V_A(N-1) \end{bmatrix}$ and represents the first horizontal beamforming vector, and $V_0, \ldots V_{N-1}$ represent the first part of the vertical beamforming vectors.

[0095] Likewise, the second 3D beamforming vector (denoted as V_B^{3D}) may be obtained by:

$$V_B^{3D}[MN \times 1] = \begin{bmatrix} V_B(0) \cdot V_N \\ \vdots \\ V_B(N-1) \cdot V_{2N-1} \end{bmatrix} \tag{12}$$

where $V_B = \begin{bmatrix} V_B(0) \\ \vdots \\ V_B(N-1) \end{bmatrix}$ and represents the second horizontal beamforming vector, and $V_N, \ldots V_{2N-1}$ represent the second part of the vertical beamforming vectors.

[0096] To better understand the process of steps 470-490 and the subsequent determination of the first and second 3D beamforming vectors, reference may be made to FIG. 12, which illustrates a diagram 1200 of determination of the first and second horizontal beamforming vectors and the first and second 3D beamforming vectors.

[0097] In addition to the above, it is to be noted that steps 410-440 of the method 400 illustrate an exemplary embodiment of step 310, which is an example rather than limitation to the present invention. Those skilled in the art will readily understand that step 310 may be implemented in any other suitable embodiments. In some embodiments, the calculation of the 2N eigenvectors as discussed above may be simplified as calculating one eigenvector. More specifically, elements of the initial channel matrix may be divided into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array. Next, 2N vertical covariance matrices of the 2N groups may be calculated. Each of the 2N vertical covariance matrices may be then averaged in a first predetermined period of time or a first predetermined frequency band. Next, a sum or a mean value of the averaging results may be calculated. Then, an eigenvector which is calculated based on the sum or the mean value may be determined as ach of the vertical beamforming vectors. In this way, all of the vertical beamforming vectors are identical. FIG. 13 illustrates a diagram 1300 of determination of the vertical beamforming vectors according to the aforesaid embodiments of the present invention.

[0098] In some alternative embodiments, elements of the initial channel matrix may be divided into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array. Next, a vertical covariance matrix of one of the 2N groups may be calculated and averaged in a first predetermined period of time or a first predetermined frequency band. Then, an eigenvector calculated based on the averaging result may be determined as each of the vertical beamforming vectors. FIG. 14 illustrates a diagram 1400 of determination of the vertical beamforming vectors according to the aforesaid embodiments of the present invention.

[0099] According to embodiments of the present invention, in addition to method 300 which illustrates an implementation of step 220 of method 200, step 220 may be implemented in several other ways. For instance, FIG. 5 illustrates a flow chart of a method 500 for determining vertical beamforming vectors and horizontal beamforming vectors according to embodiments of the invention. In embodiments of FIG. 5, both the vertical beamforming vectors and the horizontal beamforming vectors are determined from the initial channel matrix. However, it is noted that this is only for the purpose of illustrating the principles of the present invention, rather than limiting the scope thereof.

[00100] Method 500 starts from step 510, in which the vertical beamforming vectors are calculated based on the initial channel matrix. This step is similar to step 310, thus its descriptions are not detailed here. It is to be noted that the embodiments described with respect to step 310 of method 300 and steps 410-440 of method 400 also applicable to step 510.

[00101] In step 520, the horizontal beamforming vectors are calculated based on the initial channel matrix.

[00102] According to embodiments of the present invention, the horizontal beamforming vectors may be obtained in several ways. In some embodiments, the initial channel matrix may be divided into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array. Next, 2M horizontal covariance matrices of the 2M groups may be calculated and averaged in a second predetermined period of time or a second predetermined frequency band. Then, 2M eigenvectors calculated based on the averaging results may be determined as the horizontal beamforming vectors.

[00103] As an alternative, in some embodiments, the initial channel matrix may be divided into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array. 2M horizontal covariance matrices of the 2M groups may be calculated and averaged in a second predetermined period of time or a second predetermined frequency band. Next, a sum or a mean value of the averaging results may be calculated. Then, an eigenvector calculated based on the sum or the mean value may be determined as each of the horizontal beamforming vectors. In this way, all of the horizontal beamforming vectors are identical.

[00104] As a further alternative, in some embodiments, the initial channel matrix may be divided into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array. Next, a horizontal covariance matrix of one of the 2M groups may be calculated and averaged in a second predetermined period of time or a second predetermined frequency band. Then, an eigenvector calculated based on the averaging result may be determined as each of the horizontal beamforming vectors.

[00105] To better understand step 520, reference is made to FIG. 6, which illustrates a flow chart of a method 600 for determining vertical beamforming vectors and horizontal beamforming vectors according to further embodiments of the invention. The method 600 may be considered as a specific implementation of method 500 described above with reference to Fig. 5. More specifically, steps 610 corresponds to an implementation of step 510, and steps 620-650 correspond to an implementation of step 520. However, it is noted that this is only for the purpose of illustrating the principles of the present invention, rather than limiting the scope thereof.

[00106] Method 600 starts from step 610, in which the vertical beamforming vectors are calculated based on the initial channel matrix. This step is similar to steps 310 and 510, thus its descriptions are not detailed here.

[00107] Then method 600 proceeds to step 620 to calculate the horizontal beamforming vectors independent of the vertical beamforming vectors. In step 620, the initial channel matrix is divided into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array.

[00108] FIG. 15 illustrates a diagram 1500 of dividing of the initial channel matrix according to embodiments of the present invention. As shown in FIG. 15, the size of the initial channel matrix $H[N_R \times N_T]$ is $2MN \times N_T$. Thus, the initial channel matrix may be divided, according to $2M$ rows of antennas, into $2M$ groups, H_0, ...H_{M-1}, ... H_{2M-1}. Each of the H_0, ...H_{M-1}, ... H_{2M-1} corresponds to a row of antennas in the first antenna array or the second antenna array.

[00109] In step 630, 2M horizontal covariance matrices of the 2M groups are calculated.

[00110] Assuming one of the 2M groups H_0, ...H_{M-1}, ... H_{2M-1} as H_j (j=0, 1, ..., 2M-1), a corresponding horizontal covariance matrix, R_j, may be calculated as follows:

$$R_j = H_j \cdot H_j^H \tag{13}$$

where H_j^H represents conjugation of H_j.

[00111] In step 640, each of the 2M horizontal covariance matrices is averaged in a second predetermined period of time or a second predetermined frequency band.

[00112] In this step, each of the 2M horizontal covariance matrices, R_j, may be averaged in the second predetermined period of time or the second predetermined frequency band. The second predetermined period of time or the second predetermined frequency band may be referred to as the second range in context of the disclosure. The averaged R_j may be denoted as $\overline{R}_j$, j=0, 1, ..., 2M-1.

[00113] In step 650, 2M eigenvectors calculated based on the averaging results are determined as the horizontal beamforming vectors.

[00114] With respect to each of the averaged horizontal covariance matrices, a decomposition operation, such as $N \times N$ EVD, may be carried out, and an eigenvector may be obtained therefrom. By way of example, an eigenvector P_j may be calculated from the following:

$$\bar{R}_j = P_j D_j^2 P_j^H \tag{14}$$

[00115] Accordingly, 2M eigenvectors $P_0, P_1, \ldots P_{2M-1}$ may be calculated from equation (14) and may be determined as 2M horizontal beamforming vectors. The size of each of the 2M horizontal beamforming vectors $P_0, P_1, \ldots P_{2M-1}$ is $N \times 1$.

[00116] To better understand the process of steps 620-650, reference is now made to FIG. 16, in which a diagram 1600 of obtaining the horizontal beamforming vectors is illustrated. As shown in FIG. 16, the 2M horizontal beamforming vectors P_0, $P_1, \ldots P_{2M-1}$ (shown as $P_0[N \times 1], P_1[N \times 1] \ldots P_{2M-1}[N \times 1]$) are obtained from *2M* groups, $H_{2M-1}, \ldots H_{M-1}, \ldots H_0$ of the initial channel matrix $H[N_R \times N_T]$ after calculating covariance matrices (denoted as "Covar."), averaging (denoted as "Av.") and EVD. It is to be noted that in the context of the disclosure, "Covar." represents an operation of calculating a covariance matrix, and "Av." represents an operation of averaging.

[00117] In addition to the above, it is to be noted that steps 620-650 of the method 600 illustrate an exemplary embodiment of step 520, which is an example rather than limitation to the present invention. Those skilled in the art will readily understand that step 520 may be implemented in any other suitable embodiments. In some embodiments, the initial channel matrix may be divided into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array. 2M horizontal covariance matrices of the 2M groups may be calculated and averaged in a second predetermined period of time or a second predetermined frequency band. Next, a sum or a mean value of the averaging results may be calculated. Then, an eigenvector calculated based on the sum or the mean value may be determined as each of the horizontal beamforming vectors. FIG. 17 illustrates a diagram 1700 of determination of the horizontal beamforming vectors according to the aforesaid embodiments of the present invention.

[00118] In some alternative embodiments, the initial channel matrix may be divided into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array. Next, a horizontal covariance matrix of one of the 2M groups may be calculated and averaged in a second predetermined period of time or a second predetermined frequency band. Then, an eigenvector calculated based on the averaging result may be determined as each of the horizontal beamforming vectors. FIG. 18 illustrates a diagram 1800 of determination of the horizontal beamforming vectors according to the aforesaid embodiments of the present invention.

[00119] According to embodiments of the present invention, with the horizontal beamforming vectors and the vertical beamforming vectors, the first and second 3D beamforming vectors may be calculated accordingly. In some embodiments, the vertical beamforming vectors obtained at step 610 may be divided into two parts, wherein the first part is associated with the polarization of the first antenna array, and the second part is associated with the polarization of the second antenna array. Likewise, the horizontal beamforming vectors obtained at step 650 may be divided into two parts, wherein the first part is associated with the polarization of the first antenna array, and the second part is associated with the polarization of the second antenna array. Then, the first 3D beamforming vector may be calculated based on the first part of the vertical beamforming vectors and the first part of the horizontal beamforming vectors. The second 3D beamforming vector may be calculated based on the second part of the vertical beamforming vectors and the second part of horizontal beamforming vectors.

[00120] In an embodiment, the first 3D beamforming vector (denoted as $V_A^{3D}[MN \times 1]$) associated with the polarization of the first antenna array may be obtained by:

$$V_A^{3D}[MN \times 1] = \begin{bmatrix} V_0(0) \cdot P_0(0) \\ V_0(1) \cdot P_1(0) \\ \vdots \\ V_0(M-1) \cdot P_{M-1}(0) \\ V_1(0) \cdot P_0(1) \\ V_1(1) \cdot P_1(1) \\ \vdots \\ V_1(M-1) \cdot P_{M-1}(1) \\ \vdots \\ V_{N-1}(0) \cdot P_0(N-1) \\ V_{N-1}(1) \cdot P_1(N-1) \\ \vdots \\ V_{N-1}(M-1) \cdot P_{M-1}(N-1) \end{bmatrix} \tag{15}$$

where $V_0(0) \cdot P_0(0)$ corresponds to antenna location (0, 0) shown in FIG. 1;

$V_0(1) \cdot P_1(0)$ corresponds to antenna location (1, 0) shown in FIG. 1;

$V_0(M-1) \cdot P_{M-1}(0)$ corresponds to antenna location (M-1, 0) shown in FIG. 1;

$V_1(0) \cdot P_0(1)$ corresponds to antenna location (0, 1) shown in FIG. 1;

$V_1(1) \cdot P_1(1)$ corresponds to antenna location (1, 1) shown in FIG. 1;

$V_1(M-1) \cdot P_{M-1}(1)$ corresponds to antenna location (M-1, 1) shown in FIG. 1;

$V_{N-1}(0) \cdot P_0(N-1)$ corresponds to antenna location (0, N-1) shown in FIG. 1;

$V_{N-1}(1) \cdot P_1(N-1)$ corresponds to antenna location (1, N-1) shown in FIG. 1;

$V_{N-1}(M-1) \cdot P_{M-1}(N-1)$ corresponds to antenna location (M-1, N-1) shown in FIG. 1.

[00121] The second 3D beamforming vector (denoted as $V_B^{3D}[MN \times 1]$) associated with the polarization of the second antenna array may be obtained by:

$$V_B^{3D}[MN \times 1] = \begin{bmatrix} V_N(0) \cdot P_M(0) \\ V_N(1) \cdot P_{M+1}(0) \\ \vdots \\ V_N(M-1) \cdot P_{2M-1}(0) \\ V_{N+1}(0) \cdot P_M(1) \\ V_{N+1}(1) \cdot P_{M+1}(1) \\ \vdots \\ V_{N+1}(M-1) \cdot P_{2M-1}(1) \\ \vdots \\ V_{2N-1}(0) \cdot P_M(N-1) \\ V_{2N-1}(1) \cdot P_{M+1}(N-1) \\ \vdots \\ V_{2N-1}(M-1) \cdot P_{2M-1}(N-1) \end{bmatrix} \quad (16)$$

where $V_N(0) \cdot P_M(0)$ corresponds to antenna location (0, 0) shown in FIG. 1;

$V_N(1) \cdot P_{M+1}(0)$ corresponds to antenna location (1, 0) shown in FIG. 1;

$V_N(M-1) \cdot P_{2M-1}(0)$ corresponds to antenna location (M-1, 0) shown in FIG. 1;

$V_{N+1}(0) \cdot P_M(1)$ corresponds to antenna location (0, 1) shown in FIG. 1;

$V_{N+1}(1) \cdot P_{M+1}(1)$ corresponds to antenna location (1, 1) shown in FIG. 1;

$V_{N+1}(M-1) \cdot P_{2M-1}(1)$ corresponds to antenna location (M-1, 1) shown in FIG. 1;

$V_{2N-1}(0) \cdot P_M(N-1)$ corresponds to antenna location (0, N-1) shown in FIG. 1;

$V_{2N-1}(1) \cdot P_{M+1}(N-1)$ corresponds to antenna location (1, N-1) shown in FIG. 1;

$V_{2N-1}(M-1) \cdot P_{2M-1}(N-1)$ corresponds to antenna location (M-1, N-1) shown in FIG. 1.

[00122] In some embodiments, after determining the first 3D beamforming vector and the second 3D beamforming vector, the phase factor matrix may be determined based on the first 3D beamforming vector, the second 3D beamforming vector as well as the initial channel matrix. FIG. 7 illustrates a flow chart of a method 700 for determining a phase factor matrix according to such embodiments. The method 700 may be considered as a specific implementation of step 240 of method 200 described above with reference to Fig. 2. However, it is noted that this is only for the purpose of illustrating the principles of the present invention, rather than limiting the scope thereof.

[00123] Method 700 starts from step 710, in which the initial channel matrix is divided into a first channel matrix and a second channel matrix, wherein the first channel matrix is associated with the first antenna array and the second channel matrix is associated with the second antenna array.

[00124] In some embodiments, the initial channel matrix $H[N_R \times N_T]$ may be divided as below:

$$H[N_R \times N_T] = \begin{bmatrix} H_A \\ H_B \end{bmatrix} \tag{17}$$

where the first channel matrix H_A is a $MN \times N_T$ matrix and associated with the polarization of the first antenna array; and the second channel matrix H_B is a $MN \times N_T$ matrix and associated with the polarization of the second antenna array.

[00125] In step 720, a composition channel matrix is obtained based on the first 3D beamforming vector, the second 3D beamforming vector, the first channel matrix and the second channel matrix.

[00126] In some embodiments, the composition channel matrix may be obtained as follows:

$$\tilde{H}^{3D}[N_T \times 2] = [H_A^H \cdot V_A^{3D} \quad H_B^H \cdot V_B^{3D}] \tag{18}$$

where H_A^H represents conjugation of the first channel matrix H_A; H_B^H represents conjugation of the second channel matrix H_B; V_A^{3D} represents the first 3D beamforming vector; and V_B^{3D} represents the second 3D beamforming vector. FIG. 19 illustrates a diagram 1900 of obtaining the composition channel matrix according to embodiments of the present invention.

[00127] Still in reference to FIG. 7, in step 730, a composition covariance matrix of the composition channel matrix is calculated.

[00128] In some embodiments, the composition covariance matrix R_H of the composition channel matrix may be calculated as follows:

$$R_H = (\tilde{H}^{3D})^H \cdot \tilde{H}^{3D} \tag{19}$$

where $\tilde{H}^{3D}$ represents the composition channel matrix, and $(\tilde{H}^{3D})^H$ represents conjugation of the composition channel matrix $\tilde{H}^{3D}$.

[00129] In step 740, the composition covariance matrix is averaged in a third predetermined period of time or a third predetermined frequency band. According to embodiments of the present invention, the third predetermined period of time or the third predetermined frequency band may be referred to as the third range. According to embodiments of the present invention, the first range may be larger than or equal to the second range, and the second range may be larger than or equal to the third range. By way of example, the first predetermined period of time may be larger than or equal to the second predetermined period of time, and the second predetermined period of time may be larger than or equal to the third predetermined period of time. Alternatively or additionally, the first predetermined frequency band may be larger than or equal to the second predetermined frequency band, and the second predetermined frequency band may be larger than or equal to the third predetermined frequency band.

[00130] In some embodiments, the averaged composition covariance matrix may be denoted as $\bar{R}_H$.

[00131] In step 750, the phase factor matrix is determined by performing decomposition based on the averaging results.

[00132] In some embodiments, the phase factor matrix V_p may be obtained by performing EVD (for example, 2×2 EVD) on $\bar{R}_H$:

$$\bar{R}_H = V_p D_p^2 V_p^H \tag{20}$$

[00133] According to equation (20), the phase factor matrix V_p may be determined as:

$$V_p = \begin{bmatrix} V_p(0,0) & V_p(0,1) \\ V_p(1,0) & V_p(1,1) \end{bmatrix} \tag{21}$$

[00134] With the phase factor matrix V_p, as well as the first 3D beamforming vector and the second 3D beamforming vector, the beamforming parameter matrix V_F may be determined according to equation (2). In this way, the precoder may be obtained with reduced complexity. FIG. 20 illustrates a diagram 2000 of a process for determining the phase factor matrix and the beamforming parameter matrix according to the aforesaid embodiments of the present invention.

[00135] As an alternative of embodiments shown in FIG. 7, the phase factor matrix may be determined only based on the initial channel matrix, independent of the first 3D beamforming vector and the second 3D beamforming vector. FIG. 8 illustrates a flow chart of a method 800 for determining a phase factor matrix according to such embodiments. The method 800 may be considered as a specific implementation of step 240 of method 200 described above with reference to Fig. 2. However, it is noted that this is only for the purpose of illustrating the principles of the present invention, rather than limiting the scope thereof.

[00136] Method 800 starts from step 810, in which a simplified channel matrix is determined from the initial channel matrix, wherein the simplified channel matrix includes channel parameters associated with a pair of antennas that have different polarizations, wherein one of the pair of antennas belongs to the first antenna array and the other of the pair of antennas belongs to the second antenna array.

[00137] FIG. 21 illustrates a diagram 2100 of a process for determining the phase factor matrix and the beamforming parameter matrix according to the aforesaid embodiments of the present invention. As shown in FIG. 21, the pair of antennas includes a first antenna which belongs to the first antenna array and a second antenna which belongs to the second antenna array, and both the first antenna and the second antenna have the same location (M-1, 0).

[00138] It is to be noted that the pair of antennas shown in FIG. 21 is illustrated for purpose of example, rather than limitation. Those skilled in the art will understand that, as long as a first antenna belonging to the first antenna array and a second antenna belonging to the second antenna array have the same location, for example (i, j), wherein i=0, 1, …, M-1 and j=0, 1, …, N-1, the first antenna and the second antenna may be considered as "a pair of antennas."

[00139] According to embodiments of the present invention, a simplified channel matrix is a channel matrix associated with the pair of antennas. As shown in FIG. 21, the simplified channel matrix which is denoted as $\ddot{H}[N_T \times 2]$ may be obtained from the initial channel matrix, for example, by extracting related channel information about the pair of antennas from the initial channel matrix.

[00140] In step 820, a simplified covariance matrix of the simplified channel matrix is calculated. In step 830, the simplified covariance matrix is averaged in a third predetermined period of time or a third predetermined frequency band. In step 840, the phase factor matrix is determined by performing decomposition based on the averaging results.

[00141] Steps 820 to 840 are similar to steps 730 to 750, and the phase factor matrix may be obtained in a similar way as equations (19) – (21). Thus, related descriptions are not detailed here.

[00142] With the phase factor matrix V_p, as well as the first 3D beamforming vector and the second 3D beamforming vector, the beamforming parameter matrix V_F may be determined according to equation (2). In this way, the precoder may be obtained with reduced complexity.

[00143] FIG. 9 illustrates a schematic diagram of an apparatus 900 for performing beamforming in a MIMO system according to embodiments of the invention. According to embodiments of the present invention, the apparatus 900 may be implemented at a BS or other suitable node in a MIMO system, and the BS or other suitable node may comprise a first antenna array and a second antenna array. Each of the first antenna array and the second antenna array contains a plurality of antennas, and the first antenna array and the second antenna array have the same size and are cross-polarized.

[00144] As shown in FIG. 9, the apparatus 900 comprises an obtaining unit 910 configured to obtain an initial channel matrix based on reference signals received via the first and second antenna arrays from a UE, wherein the initial channel matrix includes channel parameters associated with both the first antenna array and the second antenna array; a first determining unit 920 configured to determine vertical beamforming vectors and horizontal beamforming vectors based on the initial channel matrix; a second determining unit 930 configured to determine a first three-dimensional (3D) beamforming vector and a second 3D beamforming vector based on the vertical beamforming vectors and the horizontal beamforming vectors, wherein the first 3D beamforming vector is associated with the polarization of the first antenna array, and the second 3D beamforming vector is associated with the polarization of the second antenna array; a third determining unit 940 configured to determine, at least in part based on the initial channel matrix, a phase factor matrix for polarizations of the first antenna array and the second antenna array; and a fourth determining unit 950 configured to determine a beamforming parameter matrix based on the phase factor matrix, the first 3Dbeamforming vector and the second 3D beamforming vector.

[00145] According to embodiments of the present invention, the first determining unit 620 may comprises: a vertical beamforming vector calculating unit configured to calculate the vertical beamforming vectors based on the initial channel matrix; and a horizontal beamforming vector calculating unit configured to calculate a first horizontal beamforming vector and a second horizontal beamforming vector based on the initial channel matrix and the vertical beamforming vectors.

[00146] According to embodiments of the present invention, the horizontal beamforming vector calculating unit may comprise: a horizontal composition channel matrix obtaining unit configured to obtain a horizontal composition channel matrix based on the initial channel matrix and the vertical beamforming vectors; a horizontal composition channel matrix dividing unit configured to divide the horizontal composition channel matrix into a first horizontal channel matrix and a second horizontal channel matrix, wherein the first horizontal channel matrix is associated with the first antenna array and the second horizontal channel matrix is associated with the second antenna array; a first horizontal covariance matrix calculating unit configured to calculate a first horizontal covariance matrix of the first horizontal channel matrix and a second horizontal covariance matrix of the second horizontal channel matrix; a first averaging unit configured to average each of the first horizontal covariance matrix and the second horizontal covariance matrix in a second predetermined period of time or a second predetermined frequency band; and a first horizontal beamforming vector determining unit configured to determine an eigenvector calculated based on the averaging of the first horizontal covariance matrix as the first horizontal beamforming vector, and another eigenvector calculated based on the averaging of the second horizontal covariance matrix as the second horizontal beamforming vector.

[00147] According to embodiments of the present invention, the second determining unit 630 may comprise: a first 3D beamforming vector calculating unit configured to calculate the first 3D beamforming vector based on a first part of the vertical beamforming vectors and the first horizontal beamforming vector; and a second 3D beamforming vector calculating unit configured to calculate the second 3D beamforming vector based on a second part of the vertical beamforming vectors and the second horizontal beamforming vector, wherein the first part of the vertical beamforming vectors is associated with the polarization of the first antenna array, and the second part of the vertical beamforming vectors is associated with the polarization of the second antenna array.

[00148] According to embodiments of the present invention, the first determining unit 610 may comprise: a vertical beamforming vector calculating unit configured to calculate the vertical beamforming vectors based on the initial channel matrix; and a horizontal beamforming vector calculating unit configured to calculate the horizontal beamforming vectors based on the initial channel matrix.

[00149] According to embodiments of the present invention, the horizontal beamforming vector calculating unit may comprise: a first initial channel matrix dividing unit configured to divide the initial channel matrix into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array; a second horizontal covariance matrix calculating unit configured to calculate 2M horizontal covariance matrices of the 2M groups; a second averaging unit configured to average each of the 2M horizontal covariance matrices in a second predetermined period of time or a second predetermined frequency band; and a second horizontal beamforming vector determining unit configured to determine 2M eigenvectors calculated based on the averaging results as the horizontal beamforming vectors.

[00150] According to embodiments of the present invention, the horizontal beamforming vector calculating unit may comprise: a first initial channel matrix dividing unit configured to divide the initial channel matrix into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array; a second horizontal covariance matrix calculating unit configured to calculate 2M horizontal covariance matrices of the 2M groups; a second averaging unit configured to average each of the 2M horizontal covariance matrices in a second predetermined period of time or a second predetermined frequency band; a first computing unit configured to calculate a sum or a mean value of the averaging results; and a second horizontal beamforming vector determining unit configured to determine an eigenvector calculated based on the sum or the mean value as each of the horizontal beamforming vectors.

[00151] According to embodiments of the present invention, the horizontal beamforming vector calculating unit may comprise: a first initial channel matrix dividing unit configured to divide the initial channel matrix into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array; a second horizontal covariance matrix calculating unit configured to calculate a horizontal covariance matrix of one of the 2M groups; a second averaging unit configured to average the horizontal covariance matrix in a second predetermined period of time or a second predetermined frequency band; and a second horizontal beamforming vector determining unit configured to determine an eigenvector calculated based on the averaging result as each of the horizontal beamforming vectors.

[00152] According to embodiments of the present invention, the second determining unit may comprise: a first 3D beamforming vector calculating unit configured to calculate the first 3D beamforming vector based on a first part of the vertical beamforming vectors and a first part of the horizontal beamforming vectors; and a second 3D beamforming vector calculating unit configured to calculate the second 3D beamforming vector based on a second part of the vertical beamforming vectors and a second part of the horizontal beamforming vectors, wherein the first part of the vertical beamforming vectors and the first part of the horizontal beamforming vectors are associated with the polarization of the first antenna array, and the second part of the vertical beamforming vectors and the second part of the horizontal beamforming vectors are associated with the polarization of the second antenna array.

[00153] According to embodiments of the present invention, the vertical beamforming vector calculating unit may comprise: a second initial channel matrix dividing unit configured to divide elements of the initial channel matrix into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array; a third horizontal covariance matrix calculating unit configured to calculate 2N vertical covariance matrices of the 2N groups; a third averaging unit configured to average each of the 2N vertical covariance matrices in a first predetermined period of time or a first predetermined frequency band; and a vertical beamforming vector determining unit configured to determine 2N eigenvectors calculated based on the averaging results as the vertical beamforming vectors.

[00154] According to embodiments of the present invention, the vertical beamforming vector calculating unit may comprise: a second initial channel matrix dividing unit configured to divide elements of the initial channel matrix into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array; a third horizontal covariance matrix calculating unit configured to calculate 2N vertical covariance matrices of the 2N groups; a third averaging unit configured to average each of the 2N vertical covariance matrices in a first predetermined period of time or a first predetermined frequency band; a second computing unit configured to calculating a sum or a mean value of the averaging results; and a vertical beamforming vector determining unit configured to determine an eigenvector calculated based on the sum or the mean value as each of the vertical beamforming vectors.

[00155] According to embodiments of the present invention, the vertical beamforming vector calculating unit may comprises: a second initial channel matrix dividing unit configured to divide elements of the initial channel matrix into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array; a third horizontal covariance matrix calculating unit configured to calculate a vertical covariance matrix of one of the 2N groups; a third averaging unit configured to average the vertical covariance matrix in a first predetermined period of time or a first predetermined frequency band; and a vertical beamforming vector determining unit configured to determine an eigenvector calculated based on the averaging result as each of the vertical beamforming vectors.

[00156] According to embodiments of the present invention, the third determining unit 640 may comprise: a third initial channel matrix dividing unit configured to divide the initial channel matrix into a first channel matrix and a second channel matrix, wherein the first channel matrix is associated with the first antenna array and the second channel matrix is associated with the second antenna array; a composition channel matrix obtaining unit configured to obtain a composition channel matrix based on the first 3D beamforming vector, the second 3D beamforming vector, the first channel matrix and the second channel matrix; a composition covariance matrix calculating unit configured to calculate a composition covariance matrix of the composition channel matrix; a fourth averaging unit configured to average the composition covariance matrix in a third predetermined period of time or a third predetermined frequency band; and a first phase factor matrix determining unit configured to determine the phase factor matrix by performing decomposition based on the averaging results.

[00157] According to embodiments of the present invention, the third determining unit 640 may comprise: a simplified channel matrix determining unit configured to determine a simplified channel matrix from the initial channel matrix, wherein the simplified channel matrix includes channel parameters associated with a pair of antennas that have different polarizations, wherein one of the pair of antennas belongs to the first antenna array and the other of the pair of antennas belongs to the second antenna array; a simplified covariance matrix calculating unit configured to calculate a simplified covariance matrix of the simplified channel matrix; a fifth averaging unit configured to average the simplified covariance matrix in a third predetermined period of time or a third predetermined frequency band; and a second phase factor matrix determining unit configured to determine the phase factor matrix by performing decomposition based on the averaging results.

[00158] It is also to be noted that the apparatus 900 may be respectively implemented by any suitable technique either known at present or developed in the future. Further, a single device shown in FIG. 9 may be alternatively implemented in multiple devices separately, and multiple separated devices may be implemented in a single device. The scope of the present invention is not limited in these regards.

[00159] It is noted that the apparatus 900 may be configured to implement functionalities as described with reference to FIGs.2-8. Therefore, the features discussed with respect to the methods 200-800 may apply to the corresponding components of the apparatus 900. It is further noted that the components of the apparatus 900 may be embodied in hardware, software, firmware, and/or any combination thereof. For example, the components of the apparatus 900 may be respectively implemented by a circuit, a processor or any other appropriate device. Those skilled in the art will appreciate that the aforesaid examples are only for illustration not limitation.

[00160] In some embodiment of the present disclosure, the apparatus 900 may comprise at least one processor. The at least one processor suitable for use with embodiments of the present disclosure may include, by way of example, both general and special purpose processors already known or developed in the future. The apparatus 900 may further comprise at least one memory. The at least one memory may include, for example, semiconductor memory devices, e.g., RAM, ROM, EPROM, EEPROM, and flash memory devices. The at least one memory may be used to store program of computer executable instructions. The program can be written in any high-level and/or low-level compliable or interpretable programming languages. In accordance with embodiments, the computer executable instructions may be configured, with the at least one processor, to cause the apparatus 900 to at least perform according to any of the method 200 - 800 as discussed above.

[00161] Based on the above description, the skilled in the art would appreciate that the present disclosure may be embodied in an apparatus, a method, or a computer program product. In general, the various exemplary embodiments may be implemented in hardware or special purpose circuits, software, logic or any combination thereof. For example, some aspects may be implemented in hardware, while other aspects may be implemented in firmware or software which may be executed by a controller, microprocessor or other computing device, although the disclosure is not limited thereto. While various aspects of the exemplary embodiments of this disclosure may be illustrated and described as block diagrams, flowcharts, or using some other pictorial representation, it is well understood that these blocks, apparatus, systems, techniques or methods described herein may be implemented in, as non-limiting examples, hardware, software, firmware, special purpose circuits or logic, general purpose hardware or controller or other computing devices, or some combination thereof.

[00162] The various blocks shown in FIGs. 2-8 may be viewed as method steps, and/or as operations that result from operation of computer program code, and/or as a plurality of coupled logic circuit elements constructed to carry out the associated function(s). At least some aspects of the exemplary embodiments of the disclosures may be practiced in various components such as integrated circuit chips and modules, and that the exemplary embodiments of this disclosure may be realized in an apparatus that is embodied as an integrated circuit, FPGA or ASIC that is configurable to operate in accordance with the exemplary embodiments of the present disclosure.

[00163] While this specification contains many specific implementation details, these should not be construed as limitations on the scope of any disclosure or of what may be claimed, but rather as descriptions of features that may be specific to particular embodiments of particular disclosures. Certain features that are described in this specification in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable sub-combination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a sub-combination or variation of a sub-combination.

[00164] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the embodiments described above should not be understood as requiring such separation in all embodiments, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products.

[00165] Various modifications, adaptations to the foregoing exemplary embodiments of this disclosure may become apparent to those skilled in the relevant arts in view of the foregoing description, when read in conjunction with the accompanying drawings. Any and all modifications will still fall within the scope of the non-limiting and exemplary embodiments of this disclosure. Furthermore, other embodiments of the disclosures set forth herein will come to mind to one skilled in the art to which these embodiments of the disclosure pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings.

[00166] Therefore, it is to be understood that the embodiments of the disclosure are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are used herein, they are used in a generic and descriptive sense only and not for purpose of limitation.

WHAT IS CLAIMED IS:

1. A method of performing beamforming in a Multiple Input Multiple Output (MIMO) system, wherein a base station (BS) in the MIMO system includes a first antenna array and a second antenna array, each of the first antenna array and the second antenna array contains a plurality of antennas, and the first antenna array and the second antenna array have the same size and are cross-polarized, the method comprising:

obtaining an initial channel matrix based on reference signals received via the first and second antenna arrays from user equipment (UE), wherein the initial channel matrix includes channel parameters associated with both the first antenna array and the second antenna array;

determining vertical beamforming vectors and horizontal beamforming vectors based on the initial channel matrix;

determining a first three-dimensional (3D) beamforming vector and a second 3D beamforming vector based on the vertical beamforming vectors and the horizontal beamforming vectors, wherein the first 3D beamforming vector is associated with the polarization of the first antenna array, and the second 3D beamforming vector is associated with the polarization of the second antenna array;

determining, at least in part based on the initial channel matrix, a phase factor matrix for polarizations of the first antenna array and the second antenna array; and

determining a beamforming parameter matrix based on the phase factor matrix, the first 3Dbeamforming vector and the second 3D beamforming vector.

2. The method of Claim 1, wherein determining vertical beamforming vectors and horizontal beamforming vectors based on the initial channel matrix comprises:

calculating the vertical beamforming vectors based on the initial channel matrix; and

calculating a first horizontal beamforming vector and a second horizontal beamforming vector based on the initial channel matrix and the vertical beamforming vectors.

3. The method of Claim 2, wherein calculating a first horizontal beamforming

vector and a second horizontal beamforming vector based on the initial channel matrix and the vertical beamforming vectors comprises:

obtaining a horizontal composition channel matrix based on the initial channel matrix and the vertical beamforming vectors;

dividing the horizontal composition channel matrix into a first horizontal channel matrix and a second horizontal channel matrix, wherein the first horizontal channel matrix is associated with the first antenna array and the second horizontal channel matrix is associated with the second antenna array;

calculating a first horizontal covariance matrix of the first horizontal channel matrix and a second horizontal covariance matrix of the second horizontal channel matrix;

averaging each of the first horizontal covariance matrix and the second horizontal covariance matrix in a second predetermined period of time or a second predetermined frequency band; and

determining an eigenvector calculated based on the averaging of the first horizontal covariance matrix as the first horizontal beamforming vector, and another eigenvector calculated based on the averaging of the second horizontal covariance matrix as the second horizontal beamforming vector.

4. The method of Claim 2, wherein determining a first 3D beamforming vector and a second 3D beamforming vector based on the vertical beamforming vectors and the horizontal beamforming vectors comprises:

calculating the first 3D beamforming vector based on a first part of the vertical beamforming vectors and the first horizontal beamforming vector; and

calculating the second 3D beamforming vector based on a second part of the vertical beamforming vectors and the second horizontal beamforming vector,

wherein the first part of the vertical beamforming vectors is associated with the polarization of the first antenna array, and the second part of the vertical beamforming vectors is associated with the polarization of the second antenna array.

5. The method of Claim 1, wherein determining vertical beamforming vectors and horizontal beamforming vectors based on the initial channel matrix comprises:

calculating the vertical beamforming vectors based on the initial channel matrix; and

calculating the horizontal beamforming vectors based on the initial channel matrix.

6. The method of Claim 5, wherein calculating the horizontal beamforming vectors based on the initial channel matrix comprises:

dividing the initial channel matrix into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array;

calculating 2M horizontal covariance matrices of the 2M groups;

averaging each of the 2M horizontal covariance matrices in a second predetermined period of time or a second predetermined frequency band; and

determining 2M eigenvectors calculated based on the averaging results as the horizontal beamforming vectors.

7. The method of Claim 5, wherein calculating the horizontal beamforming vectors based on the initial channel matrix comprises:

dividing the initial channel matrix into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array;

calculating 2M horizontal covariance matrices of the 2M groups;

averaging each of the 2M horizontal covariance matrices in a second predetermined period of time or a second predetermined frequency band;

calculating a sum or a mean value of the averaging results; and

determining an eigenvector calculated based on the sum or the mean value as each of the horizontal beamforming vectors.

8. The method of Claim 5, wherein calculating the horizontal beamforming vectors based on the initial channel matrix comprises:

dividing the initial channel matrix into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array;

calculating a horizontal covariance matrix of one of the 2M groups;

averaging the horizontal covariance matrix in a second predetermined period of time or a second predetermined frequency band; and

determining an eigenvector calculated based on the averaging result as each of the horizontal beamforming vectors.

9. The method of Claim 5, wherein determining the first 3D beamforming vector and the second beamforming vector based on the vertical beamforming vectors and the horizontal beamforming vectors comprises:

calculating the first 3D beamforming vector based on a first part of the vertical beamforming vectors and a first part of the horizontal beamforming vectors; and

calculating the second 3D beamforming vector based on a second part of the vertical beamforming vectors and a second part of the horizontal beamforming vectors,

wherein the first part of the vertical beamforming vectors and the first part of the horizontal beamforming vectors are associated with the polarization of the first antenna array, and the second part of the vertical beamforming vectors and the second part of the horizontal beamforming vectors are associated with the polarization of the second antenna array.

10. The method of any of Claims 2 to 9, wherein calculating the vertical beamforming vectors based on the initial channel matrix comprises:

dividing elements of the initial channel matrix into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array;

calculating 2N vertical covariance matrices of the 2N groups;

averaging each of the 2N vertical covariance matrices in a first predetermined period of time or a first predetermined frequency band; and

determining 2N eigenvectors calculated based on the averaging results as the vertical beamforming vectors.

11. The method of any of Claims 2 to 9, wherein calculating the vertical beamforming vectors based on the initial channel matrix comprises:

dividing elements of the initial channel matrix into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array;

calculating 2N vertical covariance matrices of the 2N groups;

averaging each of the 2N vertical covariance matrices in a first predetermined period of time or a first predetermined frequency band;

calculating a sum or a mean value of the averaging results; and

determining an eigenvector calculated based on the sum or the mean value as each of the vertical beamforming vectors.

12. The method of any of Claims 2 to 9, wherein calculating the vertical beamforming vectors based on the initial channel matrix comprises:

dividing elements of the initial channel matrix into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array;

calculating a vertical covariance matrix of one of the 2N groups;

averaging the vertical covariance matrix in a first predetermined period of time or a first predetermined frequency band; and

determining an eigenvector calculated based on the averaging result as each of the vertical beamforming vectors.

13. The method of Claim 1, wherein determining, at least in part based on the initial channel matrix, a phase factor matrix for polarizations of the first antenna array and the second antenna array comprises:

dividing the initial channel matrix into a first channel matrix and a second channel matrix, wherein the first channel matrix is associated with the first antenna array and the second channel matrix is associated with the second antenna array;

obtaining a composition channel matrix based on the first 3D beamforming vector, the second 3D beamforming vector, the first channel matrix and the second channel matrix;

calculating a composition covariance matrix of the composition channel matrix;

averaging the composition covariance matrix in a third predetermined period of time or a third predetermined frequency band; and

determining the phase factor matrix by performing decomposition based on the averaging results.

14. The method of Claim 1, wherein determining, at least in part based on the initial channel matrix, a phase factor matrix for polarizations of the first antenna array and the second antenna array comprises:

determining a simplified channel matrix from the initial channel matrix, wherein the simplified channel matrix includes channel parameters associated with a pair of antennas that have different polarizations, wherein one of the pair of antennas belongs to the first antenna array and the other of the pair of antennas belongs to the second antenna array;

calculating a simplified covariance matrix of the simplified channel matrix;

averaging the simplified covariance matrix in a third predetermined period of time or a third predetermined frequency band; and

determining the phase factor matrix by performing decomposition based on the averaging results.

15. An apparatus for performing beamforming in a Multiple Input Multiple Output (MIMO) system, wherein a base station (BS) in the MIMO system includes a first antenna array and a second antenna array, each of the first antenna array and the second antenna array contains a plurality of antennas, and the first antenna array and the second antenna array have the same size and are cross-polarized, the apparatus comprising:

an obtaining unit configured to obtain an initial channel matrix based on reference signals received via the first and second antenna arrays from user equipment (UE), wherein the initial channel matrix includes channel parameters associated with both the first antenna array and the second antenna array;

a first determining unit configured to determine vertical beamforming vectors and horizontal beamforming vectors based on the initial channel matrix;

a second determining unit configured to determine a first three-dimensional (3D) beamforming vector and a second 3D beamforming vector based on the vertical beamforming vectors and the horizontal beamforming vectors, wherein the first 3D beamforming vector is associated with the polarization of the first antenna array, and the second 3D beamforming vector is associated with the polarization of the second antenna array;

a third determining unit configured to determine, at least in part based on the initial channel matrix, a phase factor matrix for polarizations of the first antenna array and the second antenna array; and

a fourth determining unit configured to determine a beamforming parameter matrix based on the phase factor matrix, the first 3Dbeamforming vector and the second 3D beamforming vector.

16. The apparatus of Claim 15, wherein the first determining unit comprises:

a vertical beamforming vector calculating unit configured to calculate the vertical beamforming vectors based on the initial channel matrix; and

a horizontal beamforming vector calculating unit configured to calculate a first horizontal beamforming vector and a second horizontal beamforming vector based on the initial channel matrix and the vertical beamforming vectors.

17. The apparatus of Claim 16, wherein the horizontal beamforming vector calculating unit comprises:

a horizontal composition channel matrix obtaining unit configured to obtain a horizontal composition channel matrix based on the initial channel matrix and the vertical beamforming vectors;

a horizontal composition channel matrix dividing unit configured to divide the horizontal composition channel matrix into a first horizontal channel matrix and a second horizontal channel matrix, wherein the first horizontal channel matrix is associated with the first antenna array and the second horizontal channel matrix is associated with the second antenna array;

a first horizontal covariance matrix calculating unit configured to calculate a first horizontal covariance matrix of the first horizontal channel matrix and a second horizontal covariance matrix of the second horizontal channel matrix;

a first averaging unit configured to average each of the first horizontal covariance matrix and the second horizontal covariance matrix in a second predetermined period of time or a second predetermined frequency band; and

a first horizontal beamforming vector determining unit configured to determine an eigenvector calculated based on the averaging of the first horizontal covariance matrix as the first horizontal beamforming vector, and another eigenvector calculated based on the averaging of the second horizontal covariance matrix as the second horizontal beamforming vector.

18. The apparatus of Claim 16, wherein the second determining unit comprises:

a first 3D beamforming vector calculating unit configured to calculate the first 3D beamforming vector based on a first part of the vertical beamforming vectors and the first horizontal beamforming vector; and

a second 3D beamforming vector calculating unit configured to calculate the second 3D beamforming vector based on a second part of the vertical beamforming vectors and the second horizontal beamforming vector,

wherein the first part of the vertical beamforming vectors is associated with the polarization of the first antenna array, and the second part of the vertical beamforming vectors is associated with the polarization of the second antenna array.

19. The apparatus of Claim 15, wherein the first determining unit comprises:

a vertical beamforming vector calculating unit configured to calculate the vertical beamforming vectors based on the initial channel matrix; and

a horizontal beamforming vector calculating unit configured to calculate the horizontal beamforming vectors based on the initial channel matrix.

20. The apparatus of Claim 19, wherein the horizontal beamforming vector calculating unit comprises:

a first initial channel matrix dividing unit configured to divide the initial channel matrix into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array;

a second horizontal covariance matrix calculating unit configured to calculate 2M horizontal covariance matrices of the 2M groups;

a second averaging unit configured to average each of the 2M horizontal covariance matrices in a second predetermined period of time or a second predetermined frequency band; and

a second horizontal beamforming vector determining unit configured to determine 2M eigenvectors calculated based on the averaging results as the horizontal beamforming vectors.

21. The apparatus of Claim 19, wherein the horizontal beamforming vector calculating unit comprises:

a first initial channel matrix dividing unit configured to divide the initial channel matrix into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array;

a second horizontal covariance matrix calculating unit configured to calculate 2M horizontal covariance matrices of the 2M groups;

a second averaging unit configured to average each of the 2M horizontal covariance matrices in a second predetermined period of time or a second predetermined frequency band;

a first computing unit configured to calculate a sum or a mean value of the averaging results; and

a second horizontal beamforming vector determining unit configured to determine an eigenvector calculated based on the sum or the mean value as each of the horizontal beamforming vectors.

22. The apparatus of Claim 19, wherein the horizontal beamforming vector calculating unit comprises:

a first initial channel matrix dividing unit configured to divide the initial channel matrix into 2M groups, wherein M indicates the number of antennas in a vertical direction of the first antenna array or the second antenna array;

a second horizontal covariance matrix calculating unit configured to calculate a horizontal covariance matrix of one of the 2M groups;

a second averaging unit configured to average the horizontal covariance matrix in a second predetermined period of time or a second predetermined frequency band; and

a second horizontal beamforming vector determining unit configured to determine an eigenvector calculated based on the averaging result as each of the horizontal beamforming vectors.

23. The apparatus of Claim 19, wherein the second determining unit comprises:

a first 3D beamforming vector calculating unit configured to calculate the first 3D beamforming vector based on a first part of the vertical beamforming vectors and a first part of the horizontal beamforming vectors; and

a second 3D beamforming vector calculating unit configured to calculate the second 3D beamforming vector based on a second part of the vertical beamforming vectors and a second part of the horizontal beamforming vectors,

wherein the first part of the vertical beamforming vectors and the first part of the horizontal beamforming vectors are associated with the polarization of the first antenna array, and the second part of the vertical beamforming vectors and the second part of the horizontal beamforming vectors are associated with the polarization of the second antenna array.

24. The apparatus of any of Claims 16 to 23, wherein the vertical beamforming vector calculating unit comprises:

a second initial channel matrix dividing unit configured to divide elements of the initial channel matrix into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array;

a third horizontal covariance matrix calculating unit configured to calculate 2N vertical covariance matrices of the 2N groups;

a third averaging unit configured to average each of the 2N vertical covariance matrices in a first predetermined period of time or a first predetermined frequency band; and

a vertical beamforming vector determining unit configured to determine 2N eigenvectors calculated based on the averaging results as the vertical beamforming vectors.

25. The apparatus of any of Claims 16 to 23, wherein the vertical beamforming vector calculating unit comprises:

a second initial channel matrix dividing unit configured to divide elements of the initial channel matrix into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array;

a third horizontal covariance matrix calculating unit configured to calculate 2N vertical covariance matrices of the 2N groups;

a third averaging unit configured to average each of the 2N vertical covariance matrices in a first predetermined period of time or a first predetermined frequency band;

a second computing unit configured to calculating a sum or a mean value of the averaging results; and

a vertical beamforming vector determining unit configured to determine an eigenvector calculated based on the sum or the mean value as each of the vertical beamforming vectors.

26. The apparatus of any of Claims 16 to 23, wherein the vertical beamforming vector calculating unit comprises:

a second initial channel matrix dividing unit configured to divide elements of the initial channel matrix into 2N groups, wherein N indicates the number of antennas in a horizontal direction of the first antenna array or the second antenna array;

a third horizontal covariance matrix calculating unit configured to calculate a vertical covariance matrix of one of the 2N groups;

a third averaging unit configured to average the vertical covariance matrix in a first predetermined period of time or a first predetermined frequency band; and

a vertical beamforming vector determining unit configured to determine an eigenvector calculated based on the averaging result as each of the vertical beamforming vectors.

27. The apparatus of Claim 15, wherein the third determining unit comprises:

a third initial channel matrix dividing unit configured to divide the initial channel matrix into a first channel matrix and a second channel matrix, wherein the first channel matrix is associated with the first antenna array and the second channel matrix is associated with the second antenna array;

a composition channel matrix obtaining unit configured to obtain a composition channel matrix based on the first 3D beamforming vector, the second 3D beamforming vector, the first channel matrix and the second channel matrix;

a composition covariance matrix calculating unit configured to calculate a composition covariance matrix of the composition channel matrix;

a fourth averaging unit configured to average the composition covariance matrix in a third predetermined period of time or a third predetermined frequency band; and

a first phase factor matrix determining unit configured to determine the phase factor matrix by performing decomposition based on the averaging results.

28. The apparatus of Claim 15, wherein the third determining unit comprises:

a simplified channel matrix determining unit configured to determine a simplified channel matrix from the initial channel matrix, wherein the simplified channel matrix includes channel parameters associated with a pair of antennas that have different polarizations, wherein one of the pair of antennas belongs to the first antenna array and the other of the pair of antennas belongs to the second antenna array;

a simplified covariance matrix calculating unit configured to calculate a simplified covariance matrix of the simplified channel matrix;

a fifth averaging unit configured to average the simplified covariance matrix in a third predetermined period of time or a third predetermined frequency band; and

a second phase factor matrix determining unit configured to determine the phase factor matrix by performing decomposition based on the averaging results.

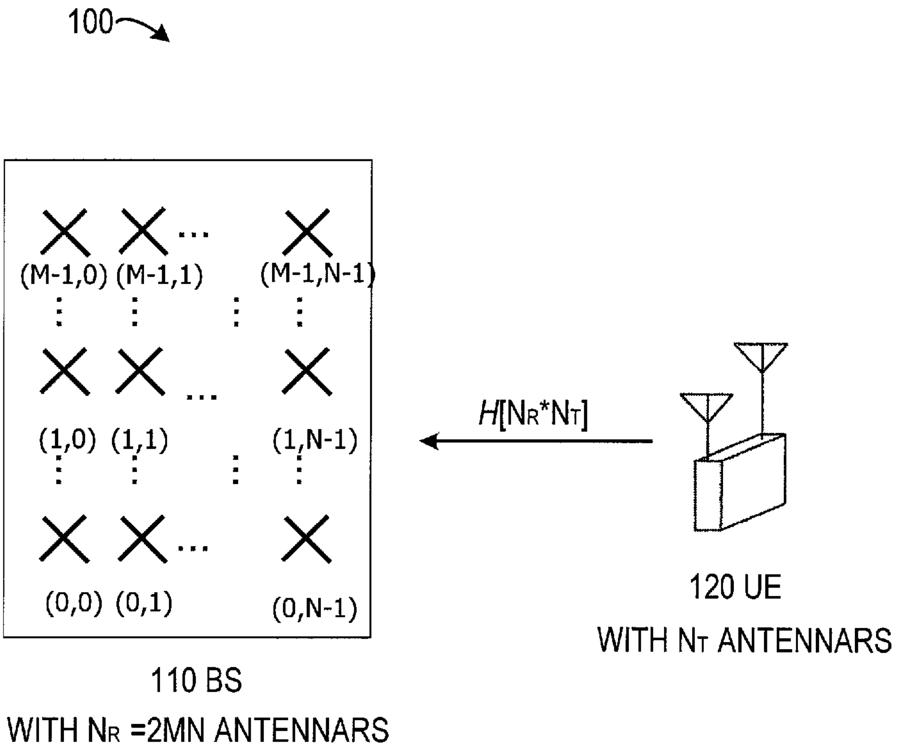
100
(M-1,0)
(M-1,1)
(M-1,N-1)
(1,0)
(1,1)
(1,N-1)
(0,0)
(0,1)
(0,N-1)
H[NR*NT]
110 BS
WITH NR =2MN ANTENNARS
120 UE
WITH NT ANTENNARS

FIG. 1

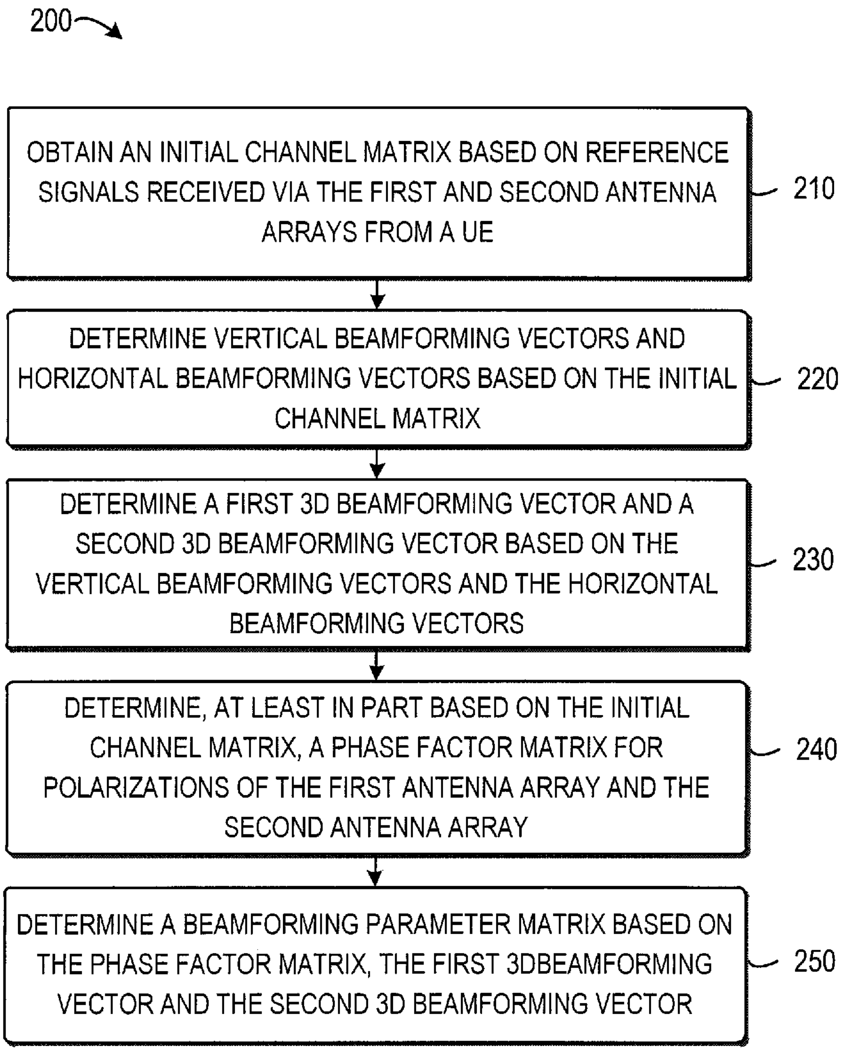
200
OBTAIN AN INITIAL CHANNEL MATRIX BASED ON REFERENCE SIGNALS RECEIVED VIA THE FIRST AND SECOND ANTENNA ARRAYS FROM A UE
210
DETERMINE VERTICAL BEAMFORMING VECTORS AND HORIZONTAL BEAMFORMING VECTORS BASED ON THE INITIAL CHANNEL MATRIX
220
DETERMINE A FIRST 3D BEAMFORMING VECTOR AND A SECOND 3D BEAMFORMING VECTOR BASED ON THE VERTICAL BEAMFORMING VECTORS AND THE HORIZONTAL BEAMFORMING VECTORS
230
DETERMINE, AT LEAST IN PART BASED ON THE INITIAL CHANNEL MATRIX, A PHASE FACTOR MATRIX FOR POLARIZATIONS OF THE FIRST ANTENNA ARRAY AND THE SECOND ANTENNA ARRAY
240
DETERMINE A BEAMFORMING PARAMETER MATRIX BASED ON THE PHASE FACTOR MATRIX, THE FIRST 3DBEAMFORMING VECTOR AND THE SECOND 3D BEAMFORMING VECTOR
250

FIG. 2

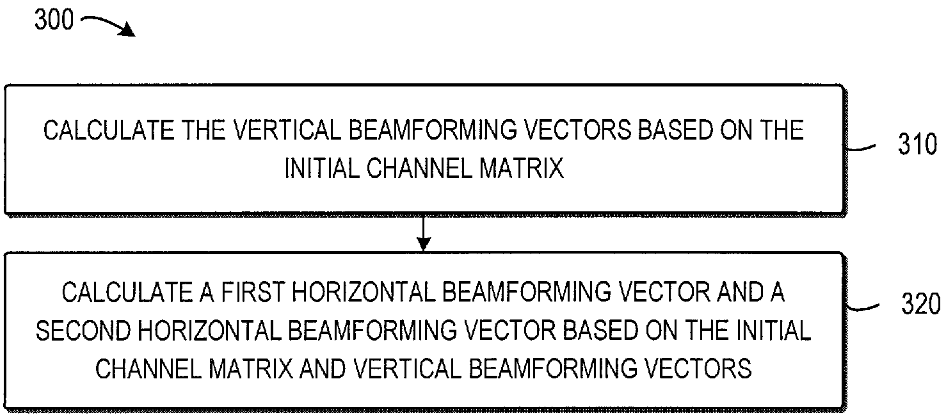
300
CALCULATE THE VERTICAL BEAMFORMING VECTORS BASED ON THE INITIAL CHANNEL MATRIX
310
CALCULATE A FIRST HORIZONTAL BEAMFORMING VECTOR AND A SECOND HORIZONTAL BEAMFORMING VECTOR BASED ON THE INITIAL CHANNEL MATRIX AND VERTICAL BEAMFORMING VECTORS
320

FIG. 3

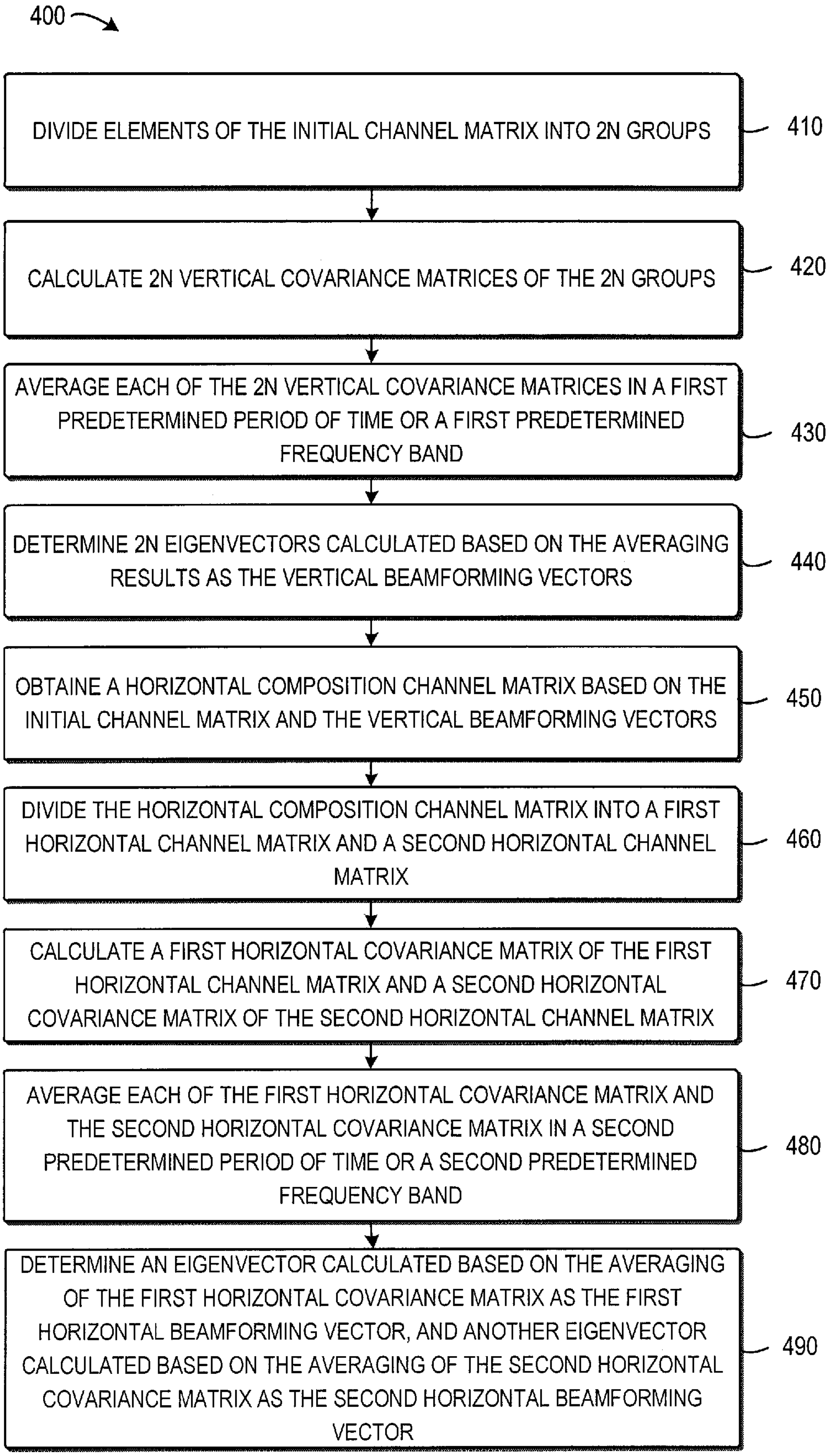
400
DIVIDE ELEMENTS OF THE INITIAL CHANNEL MATRIX INTO 2N GROUPS
410
CALCULATE 2N VERTICAL COVARIANCE MATRICES OF THE 2N GROUPS
420
AVERAGE EACH OF THE 2N VERTICAL COVARIANCE MATRICES IN A FIRST PREDETERMINED PERIOD OF TIME OR A FIRST PREDETERMINED FREQUENCY BAND
430
DETERMINE 2N EIGENVECTORS CALCULATED BASED ON THE AVERAGING RESULTS AS THE VERTICAL BEAMFORMING VECTORS
440
OBTAINE A HORIZONTAL COMPOSITION CHANNEL MATRIX BASED ON THE INITIAL CHANNEL MATRIX AND THE VERTICAL BEAMFORMING VECTORS
450
DIVIDE THE HORIZONTAL COMPOSITION CHANNEL MATRIX INTO A FIRST HORIZONTAL CHANNEL MATRIX AND A SECOND HORIZONTAL CHANNEL MATRIX
460
CALCULATE A FIRST HORIZONTAL COVARIANCE MATRIX OF THE FIRST HORIZONTAL CHANNEL MATRIX AND A SECOND HORIZONTAL COVARIANCE MATRIX OF THE SECOND HORIZONTAL CHANNEL MATRIX
470
AVERAGE EACH OF THE FIRST HORIZONTAL COVARIANCE MATRIX AND THE SECOND HORIZONTAL COVARIANCE MATRIX IN A SECOND PREDETERMINED PERIOD OF TIME OR A SECOND PREDETERMINED FREQUENCY BAND
480
DETERMINE AN EIGENVECTOR CALCULATED BASED ON THE AVERAGING OF THE FIRST HORIZONTAL COVARIANCE MATRIX AS THE FIRST HORIZONTAL BEAMFORMING VECTOR, AND ANOTHER EIGENVECTOR CALCULATED BASED ON THE AVERAGING OF THE SECOND HORIZONTAL COVARIANCE MATRIX AS THE SECOND HORIZONTAL BEAMFORMING VECTOR
490

FIG. 4

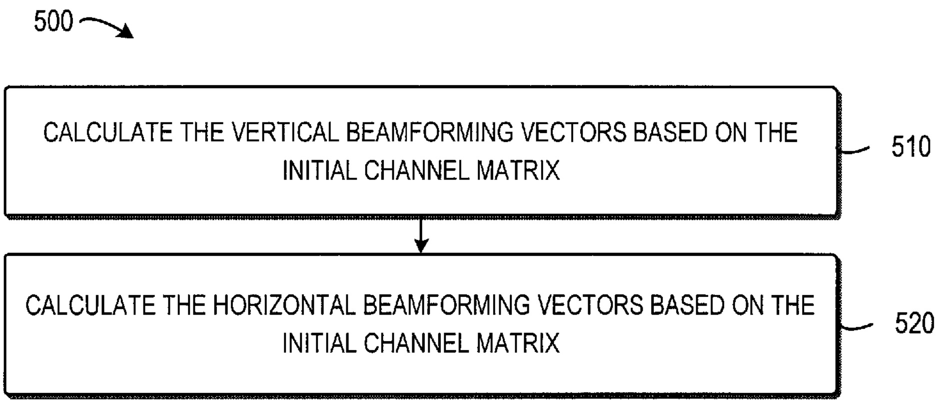
500
CALCULATE THE VERTICAL BEAMFORMING VECTORS BASED ON THE INITIAL CHANNEL MATRIX
510
CALCULATE THE HORIZONTAL BEAMFORMING VECTORS BASED ON THE INITIAL CHANNEL MATRIX
520

FIG. 5

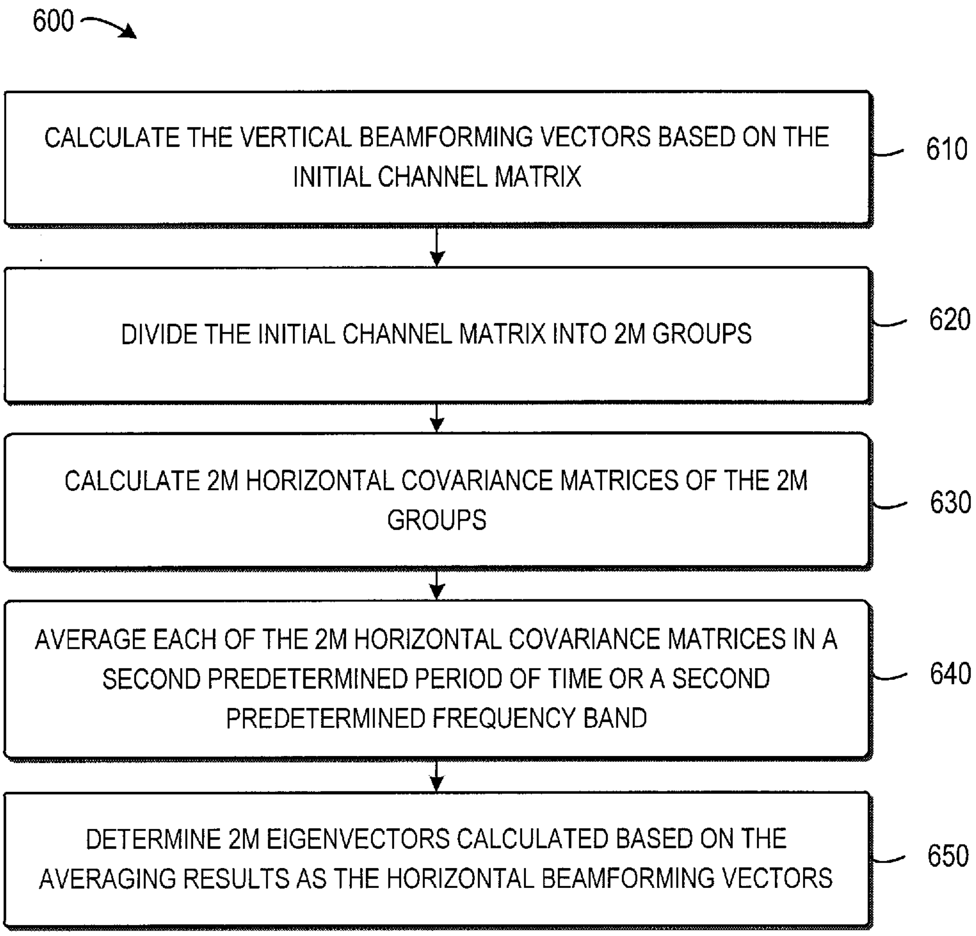
600
CALCULATE THE VERTICAL BEAMFORMING VECTORS BASED ON THE INITIAL CHANNEL MATRIX
610
DIVIDE THE INITIAL CHANNEL MATRIX INTO 2M GROUPS
620
CALCULATE 2M HORIZONTAL COVARIANCE MATRICES OF THE 2M GROUPS
630
AVERAGE EACH OF THE 2M HORIZONTAL COVARIANCE MATRICES IN A SECOND PREDETERMINED PERIOD OF TIME OR A SECOND PREDETERMINED FREQUENCY BAND
640
DETERMINE 2M EIGENVECTORS CALCULATED BASED ON THE AVERAGING RESULTS AS THE HORIZONTAL BEAMFORMING VECTORS
650

FIG. 6

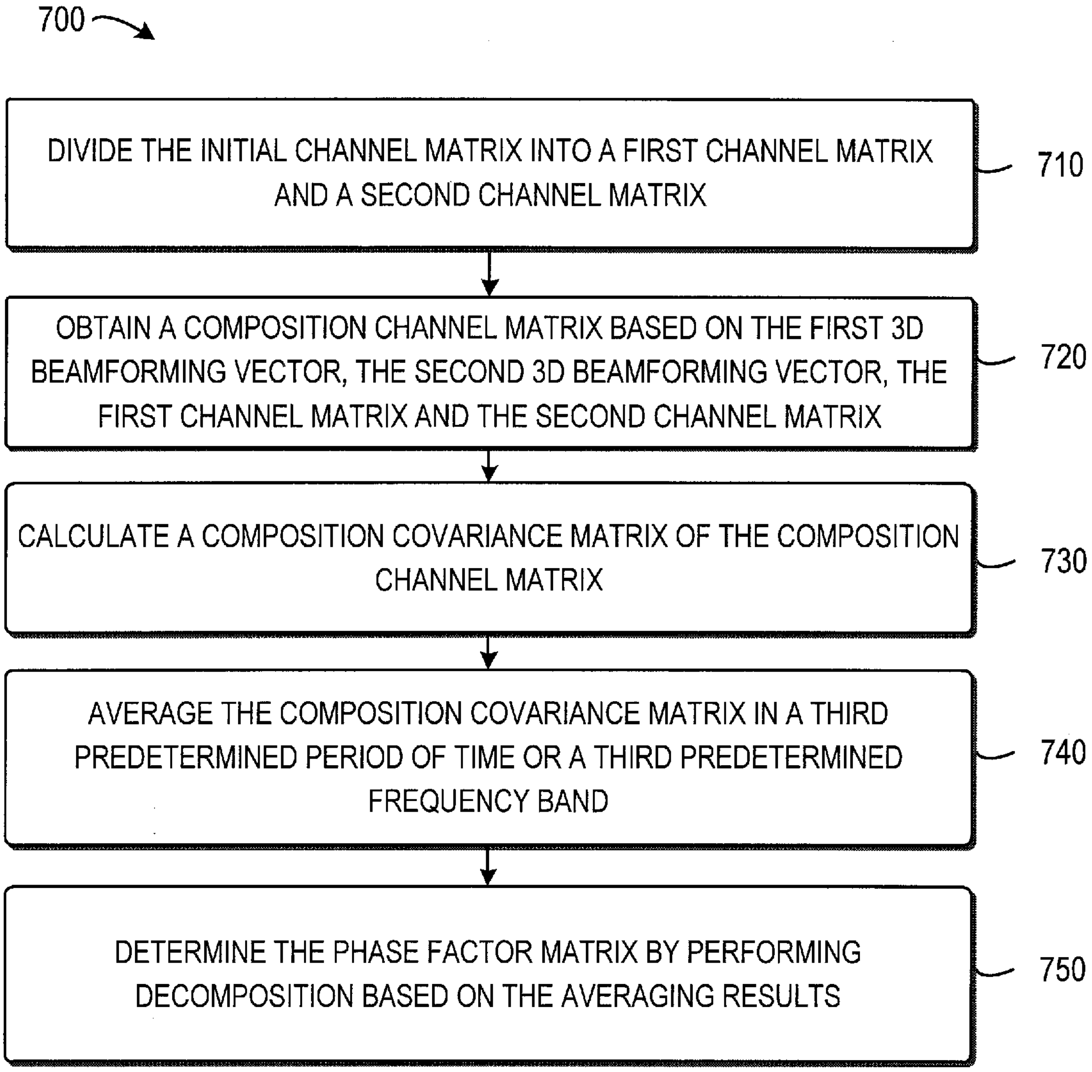
700
DIVIDE THE INITIAL CHANNEL MATRIX INTO A FIRST CHANNEL MATRIX AND A SECOND CHANNEL MATRIX
710
OBTAIN A COMPOSITION CHANNEL MATRIX BASED ON THE FIRST 3D BEAMFORMING VECTOR, THE SECOND 3D BEAMFORMING VECTOR, THE FIRST CHANNEL MATRIX AND THE SECOND CHANNEL MATRIX
720
CALCULATE A COMPOSITION COVARIANCE MATRIX OF THE COMPOSITION CHANNEL MATRIX
730
AVERAGE THE COMPOSITION COVARIANCE MATRIX IN A THIRD PREDETERMINED PERIOD OF TIME OR A THIRD PREDETERMINED FREQUENCY BAND
740
DETERMINE THE PHASE FACTOR MATRIX BY PERFORMING DECOMPOSITION BASED ON THE AVERAGING RESULTS
750

FIG. 7

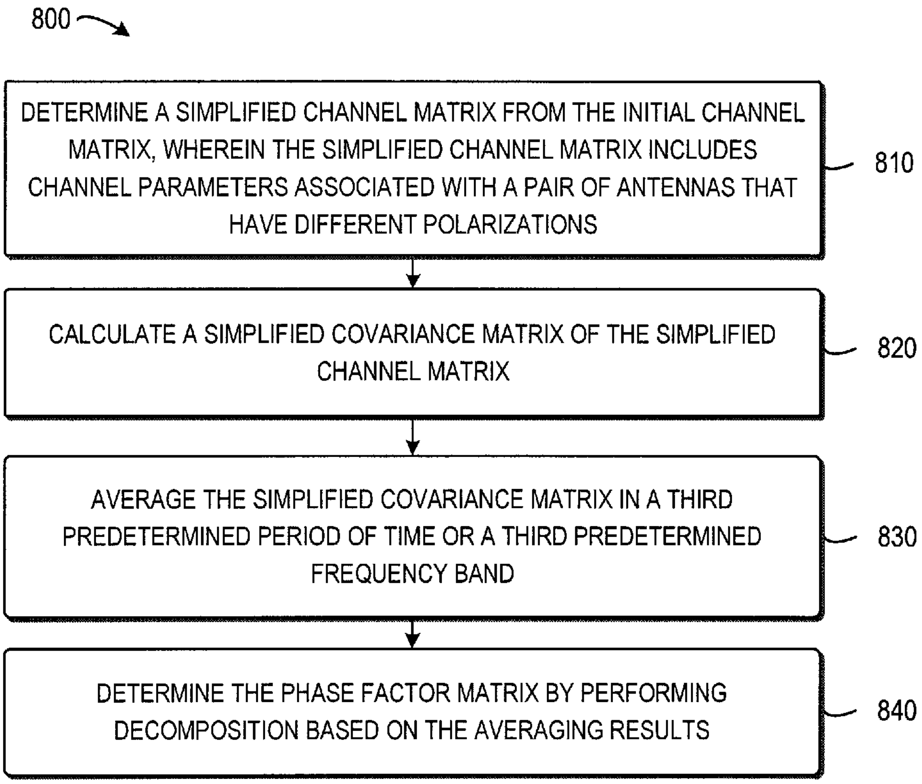
800
DETERMINE A SIMPLIFIED CHANNEL MATRIX FROM THE INITIAL CHANNEL MATRIX, WHEREIN THE SIMPLIFIED CHANNEL MATRIX INCLUDES CHANNEL PARAMETERS ASSOCIATED WITH A PAIR OF ANTENNAS THAT HAVE DIFFERENT POLARIZATIONS
810
CALCULATE A SIMPLIFIED COVARIANCE MATRIX OF THE SIMPLIFIED CHANNEL MATRIX
820
AVERAGE THE SIMPLIFIED COVARIANCE MATRIX IN A THIRD PREDETERMINED PERIOD OF TIME OR A THIRD PREDETERMINED FREQUENCY BAND
830
DETERMINE THE PHASE FACTOR MATRIX BY PERFORMING DECOMPOSITION BASED ON THE AVERAGING RESULTS
840

FIG. 8

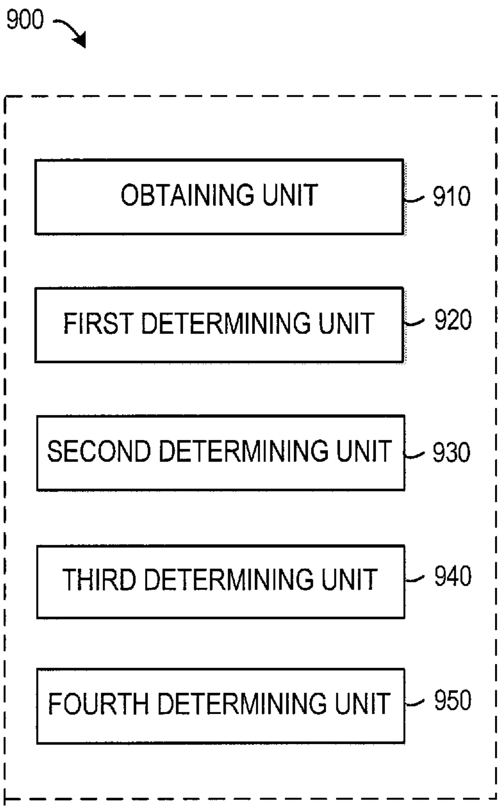
900
OBTAINING UNIT
910
FIRST DETERMINING UNIT
920
SECOND DETERMINING UNIT
930
THIRD DETERMINING UNIT
940
FOURTH DETERMINING UNIT
950

FIG. 9

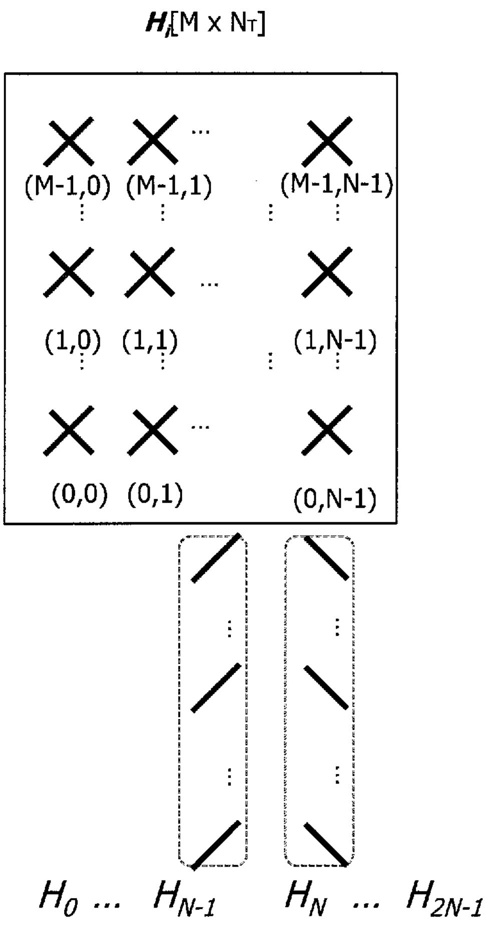

FIG. 10A

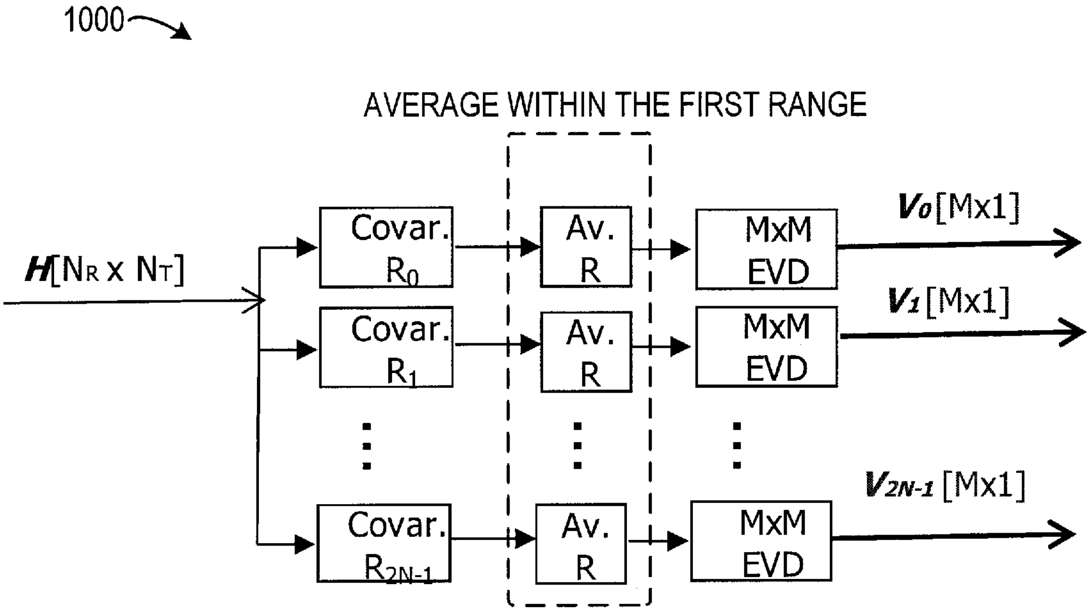

FIG. 10B

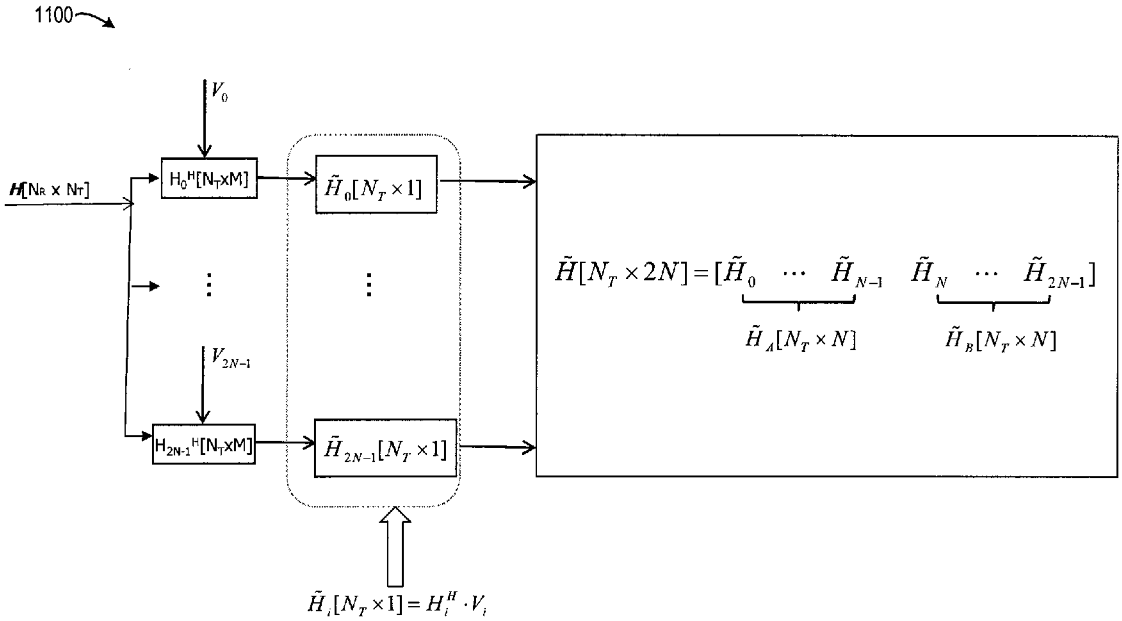
1100
V_0
$\boldsymbol{H}$[N_R x N_T]
$H_0^H[N_T x M]$
$\tilde{H}_0[N_T \times 1]$
V_{2N-1}
$H_{2N-1}^H[N_T x M]$
$\tilde{H}_{2N-1}[N_T \times 1]$
$\tilde{H}[N_T \times 2N] = [\underbrace{\tilde{H}_0 \cdots \tilde{H}_{N-1}}_{\tilde{H}_A[N_T \times N]} \underbrace{\tilde{H}_N \cdots \tilde{H}_{2N-1}}_{\tilde{H}_B[N_T \times N]}]$
$\tilde{H}_i[N_T \times 1] = H_i^H \cdot V_i$

FIG. 11

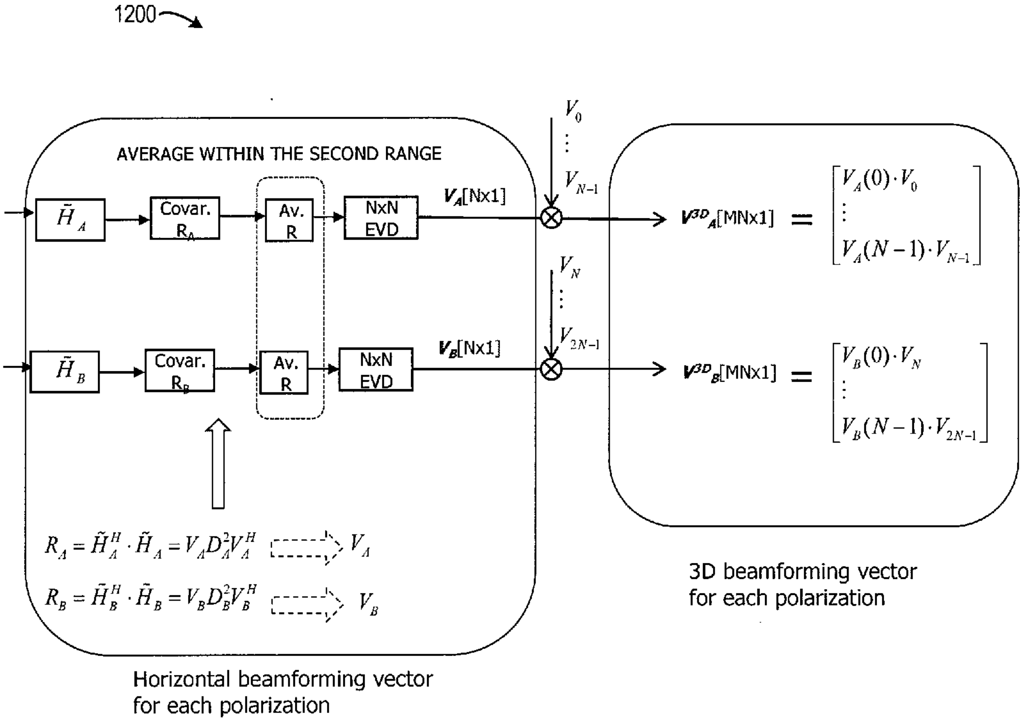
1200
AVERAGE WITHIN THE SECOND RANGE
$\tilde{H}_A$
Covar. R_A
Av. R
NxN EVD
$\boldsymbol{V_A}$[Nx1]
V_0
V_{N-1}
$\boldsymbol{V^{3D}_A}$[MNx1] $= \begin{bmatrix} V_A(0) \cdot V_0 \\ \vdots \\ V_A(N-1) \cdot V_{N-1} \end{bmatrix}$
$\tilde{H}_B$
Covar. R_B
Av. R
NxN EVD
$\boldsymbol{V_B}$[Nx1]
V_N
V_{2N-1}
$\boldsymbol{V^{3D}_B}$[MNx1] $= \begin{bmatrix} V_B(0) \cdot V_N \\ \vdots \\ V_B(N-1) \cdot V_{2N-1} \end{bmatrix}$
$R_A = \tilde{H}_A^H \cdot \tilde{H}_A = V_A D_A^2 V_A^H \Rightarrow V_A$
$R_B = \tilde{H}_B^H \cdot \tilde{H}_B = V_B D_B^2 V_B^H \Rightarrow V_B$
Horizontal beamforming vector for each polarization
3D beamforming vector for each polarization

FIG. 12

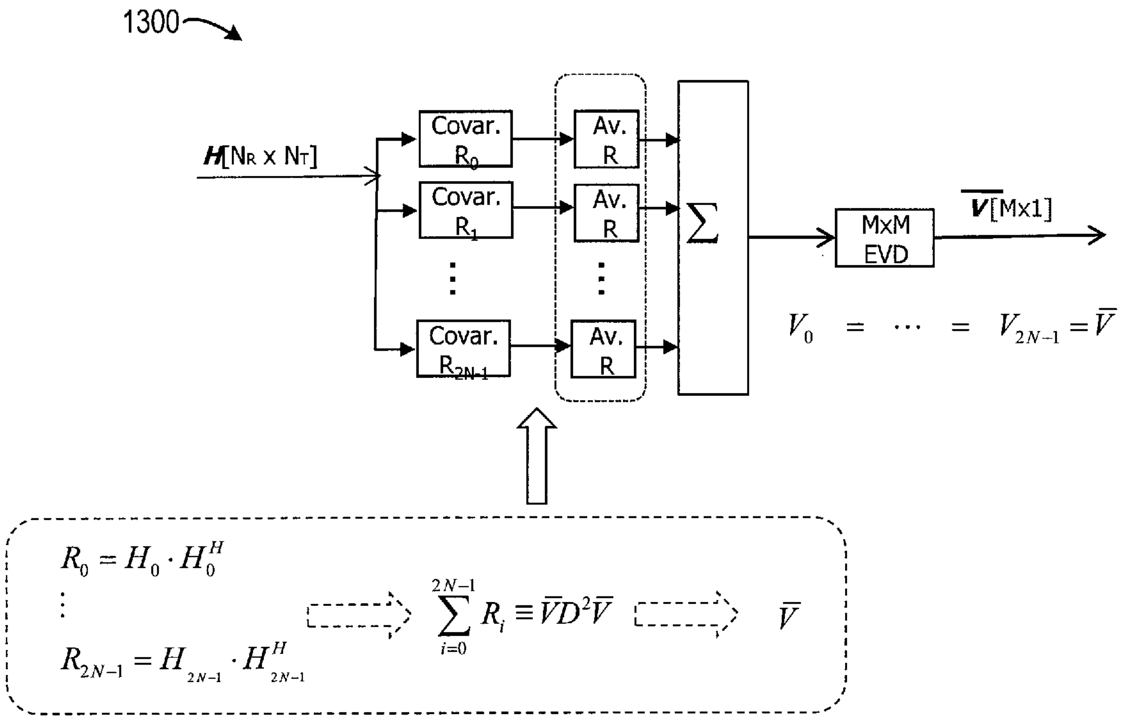
1300
$H[N_R \times N_T]$
Covar. R_0
Covar. R_1
Covar. R_{2N-1}
Av. R
Av. R
Av. R
$\sum$
MxM EVD
$\overline{V}[Mx1]$
$V_0 = \cdots = V_{2N-1} = \overline{V}$
$R_0 = H_0 \cdot H_0^H$
$R_{2N-1} = H_{2N-1} \cdot H_{2N-1}^H$
$\sum_{i=0}^{2N-1} R_i \equiv \overline{V} D^2 \overline{V}$
$\overline{V}$

FIG. 13

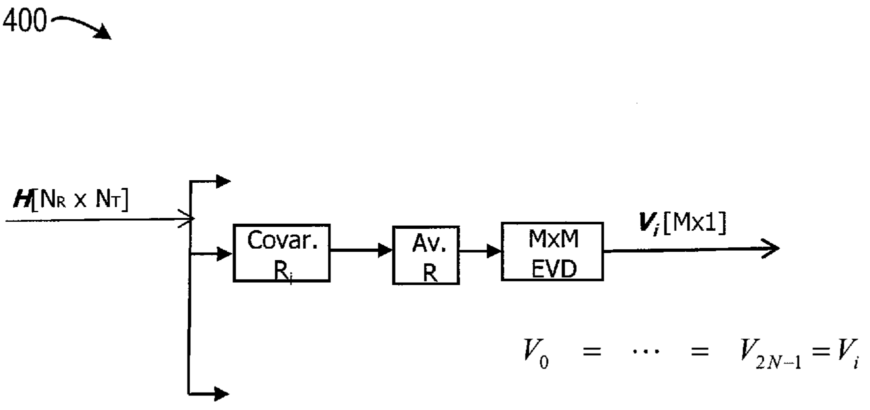
1400
$H[N_R \times N_T]$
Covar. R_i
Av. R
MxM EVD
$V_i[Mx1]$
$V_0 = \cdots = V_{2N-1} = V_i$

FIG. 14

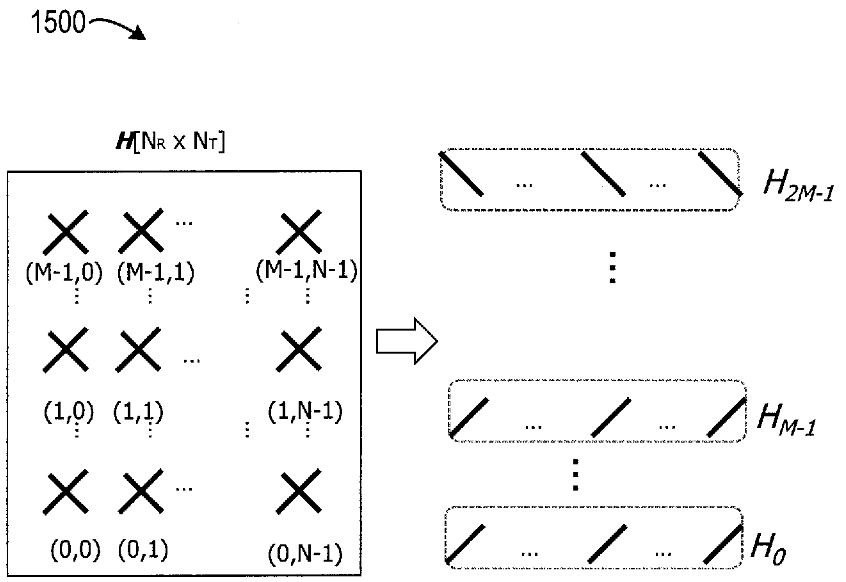

FIG. 15

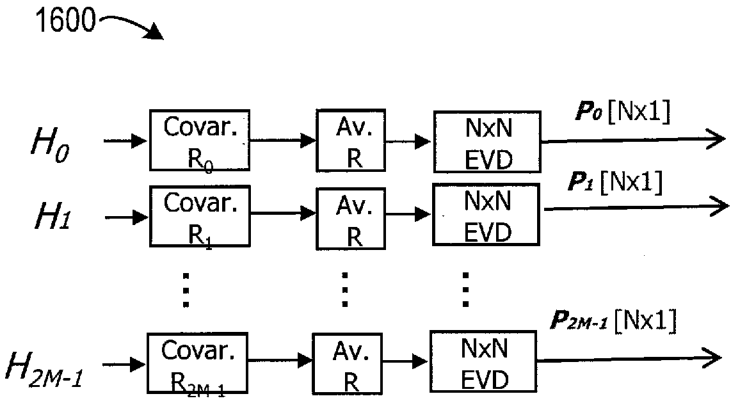

FIG. 16

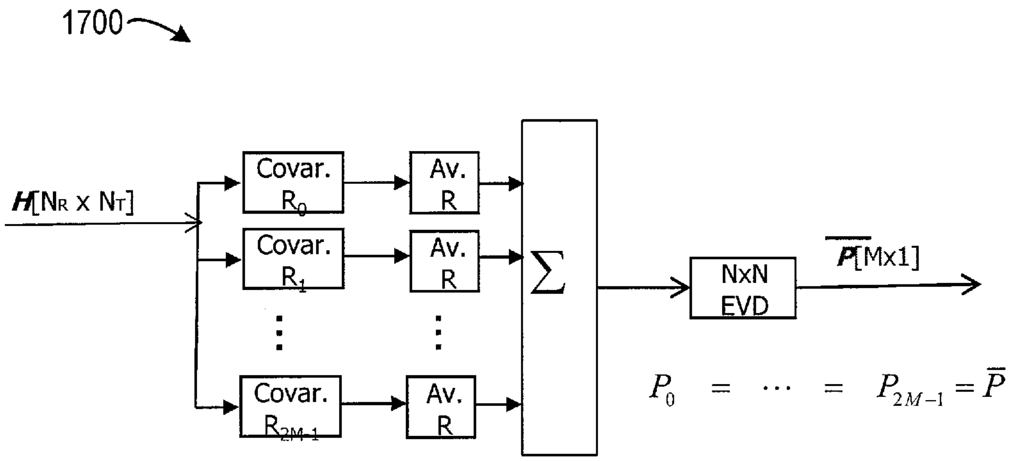

FIG. 17

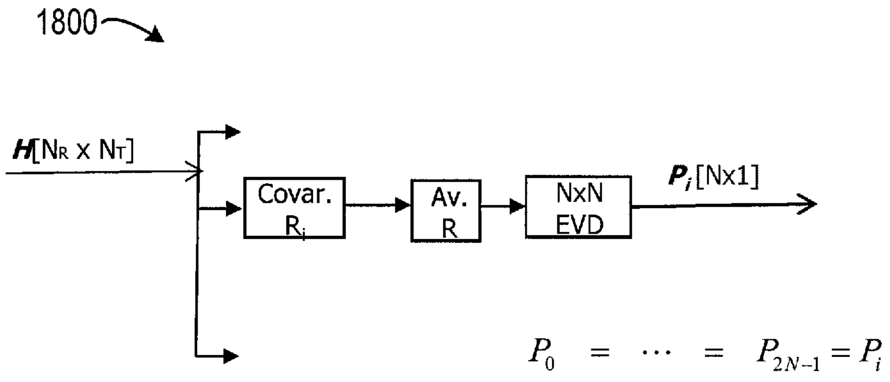

FIG. 18

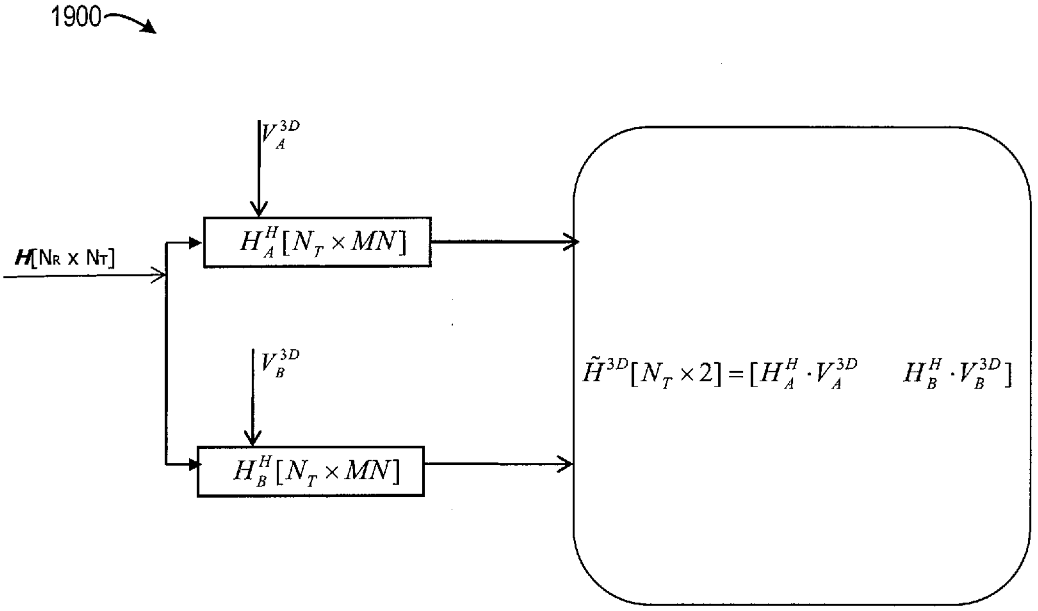

FIG. 19

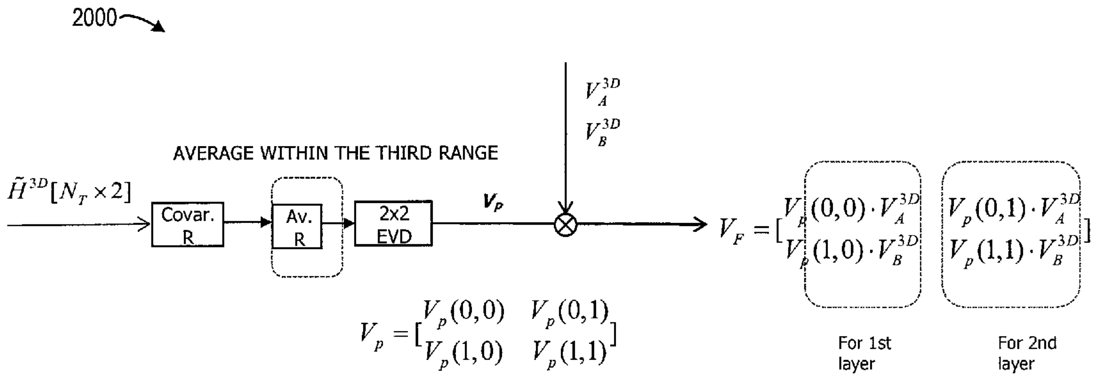

FIG. 20

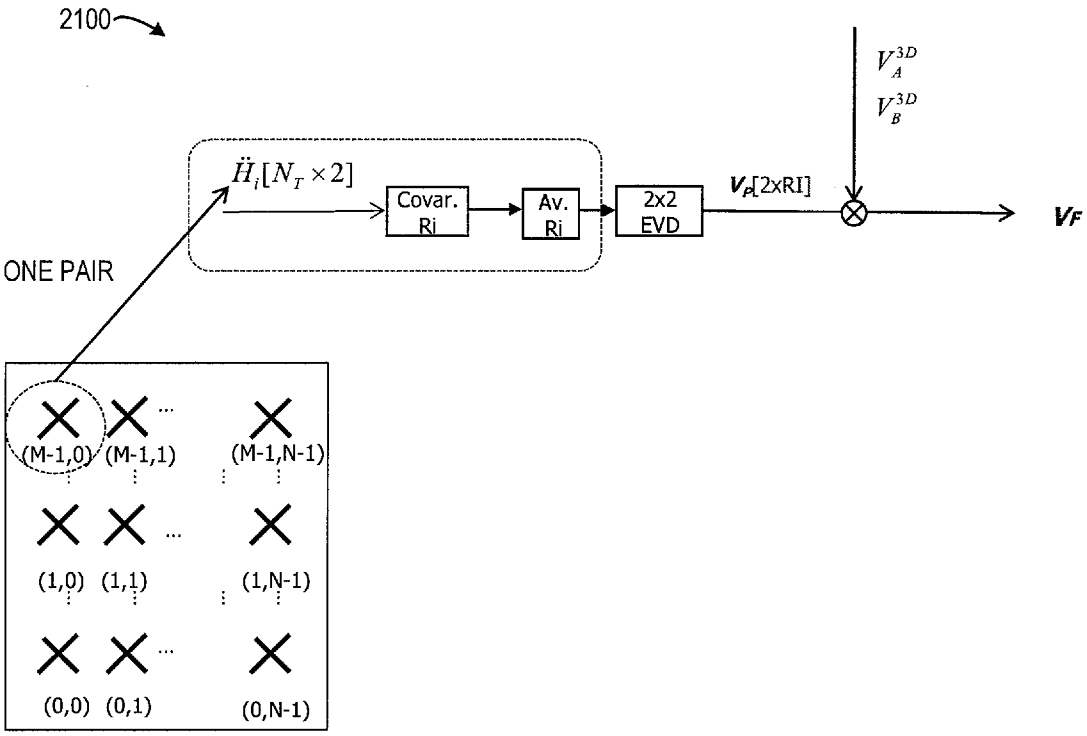
2100
V_A^{3D}
V_B^{3D}
$\ddot{H}_i[N_T \times 2]$
Covar. Ri
Av. Ri
2x2 EVD
$V_P[2xRI]$
V_F
ONE PAIR
(M-1,0)
(M-1,1)
(M-1,N-1)
(1,0)
(1,1)
(1,N-1)
(0,0)
(0,1)
(0,N-1)

FIG. 21

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2015/084246

A. CLASSIFICATION OF SUBJECT MATTER

H04B 7/04(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)

H04W; H04B

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

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

CNPAT, WPI,EPODOC, 3GPP, CNKI:matrix, initial, beamform+, phase, 3D, three-dimensional, array, polarization, MIMO, vertical, horizontal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ALCATEL-LUCENT et al. "Performance of Rel 12 AAS for 3D UMa and 3D UMi scenarios" *3GPP TSG RAN WG1 Meeting #79,* 21 November 2014 (2014-11-21), page 1 section 2 to page 5 section 3 and appendix	1-28
A	US 2015092621 A1 (BROADCOM CORPORATION) 02 April 2015 (2015-04-02) the whole document	1-28
A	US 2004081074 A1 (KABUSHIKI KAISHA TOSHIBA) 29 April 2004 (2004-04-29) the whole document	1-28
A	QUALCOMM INCORPORATED. "Performance of Rel-12 DL MIMO using 3D-UMa and 3D-UMi" *3GPP TSG-RAN WG1 #79,* 21 November 2014 (2014-11-21), pages 1 to 3	1-28

☐ 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 another citation or other special reason (as specified)
"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed
"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&"	document member of the same patent family

Date of the actual completion of the international search

22 March 2016

Date of mailing of the international search report

14 April 2016

Name and mailing address of the ISA/CN

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Authorized officer

CHENG,Qian

Telephone No. **(86-10)62413341**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2015/084246

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
US 2015092621 A1	02 April 2015	None	
US 2004081074 A1	29 April 2004	GB 0219056 D0	25 September 2002
		EP 1863241 A2	05 December 2007
		CN 1579077 A	09 February 2005
		GB 2392065 A	18 February 2004
		EP 1392029 A1	25 February 2004
		WO 2004017586 A1	26 February 2004
		JP 2005536139 A	24 November 2005