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# United States Patent [19]

Kuwahara

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[54] **POSITIONING APPARATUS USED IN A CELLULAR COMMUNICATION SYSTEM AND CAPABLE OF CARRYING OUT A POSITIONING WITH A HIGH ACCURACY IN URBAN AREA**

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[7] ..... **H04Q 7/20**; H04Q 7/36; H04B 7/02

[52] **U.S. Cl.** ..... **455/456**; 455/457; 455/561; 455/562; 340/988; 340/991; 340/993; 342/58; 342/109; 342/450; 342/451; 342/457

[58] **Field of Search** ..... 455/456, 457, 455/561, 417, 562, 132; 342/357.01, 450, 457, 58, 109, 113, 115, 451, 454, 461; 340/988, 991, 993

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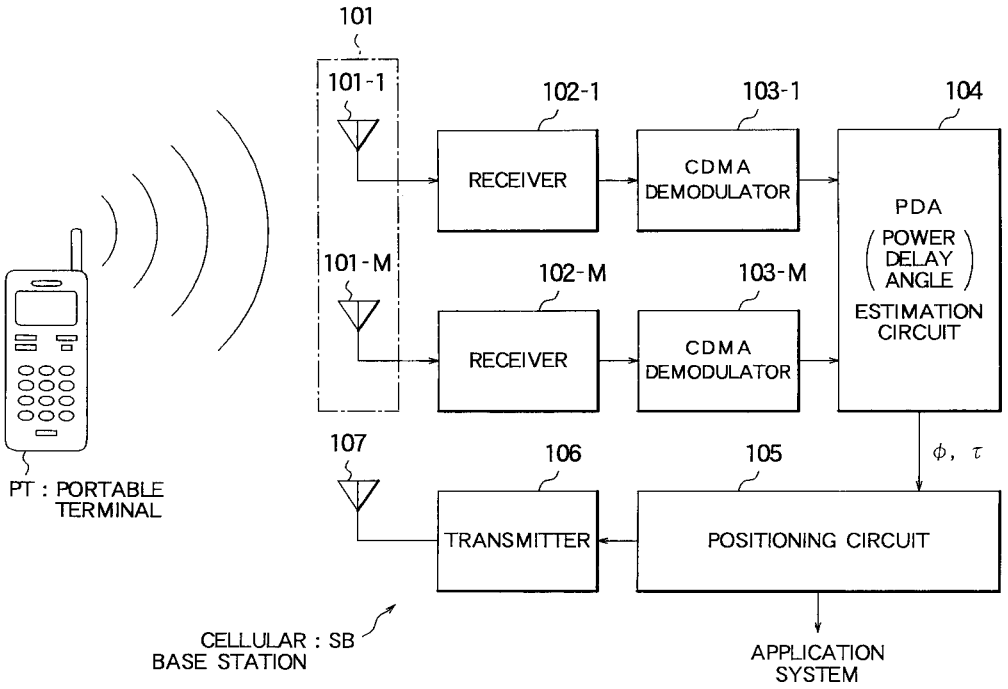
*Assistant Examiner*—Simon Nguyen
*Attorney, Agent, or Firm*—Ostrolenk, Faber, Gerb & Soffen, LLP

[57] **ABSTRACT**

A positioning apparatus is provided in a cellular base station for positioning a portable terminal in a cell covered by the cellular base station. The positioning apparatus has a base position indicative of a position of the cellular base station on a map. The positioning apparatus comprises an array antenna for receiving a transmission signal transmitted by the portable terminal to output a plurality of reception signals. A receiver section translates the reception signals into a plurality of baseband signals to demodulate the baseband signals into a plurality of demodulated signals. An estimation section estimates incident direction and delay time of the transmission signal on the basis of the demodulated signals to output an estimation result indicative of the incident direction and the delay time. A position calculating means calculates a terminal position of the portable terminal on the map in accordance with the estimation result and the base position to output a terminal position signal indicative of the terminal position.

**8 Claims, 8 Drawing Sheets**






APPLE 1007

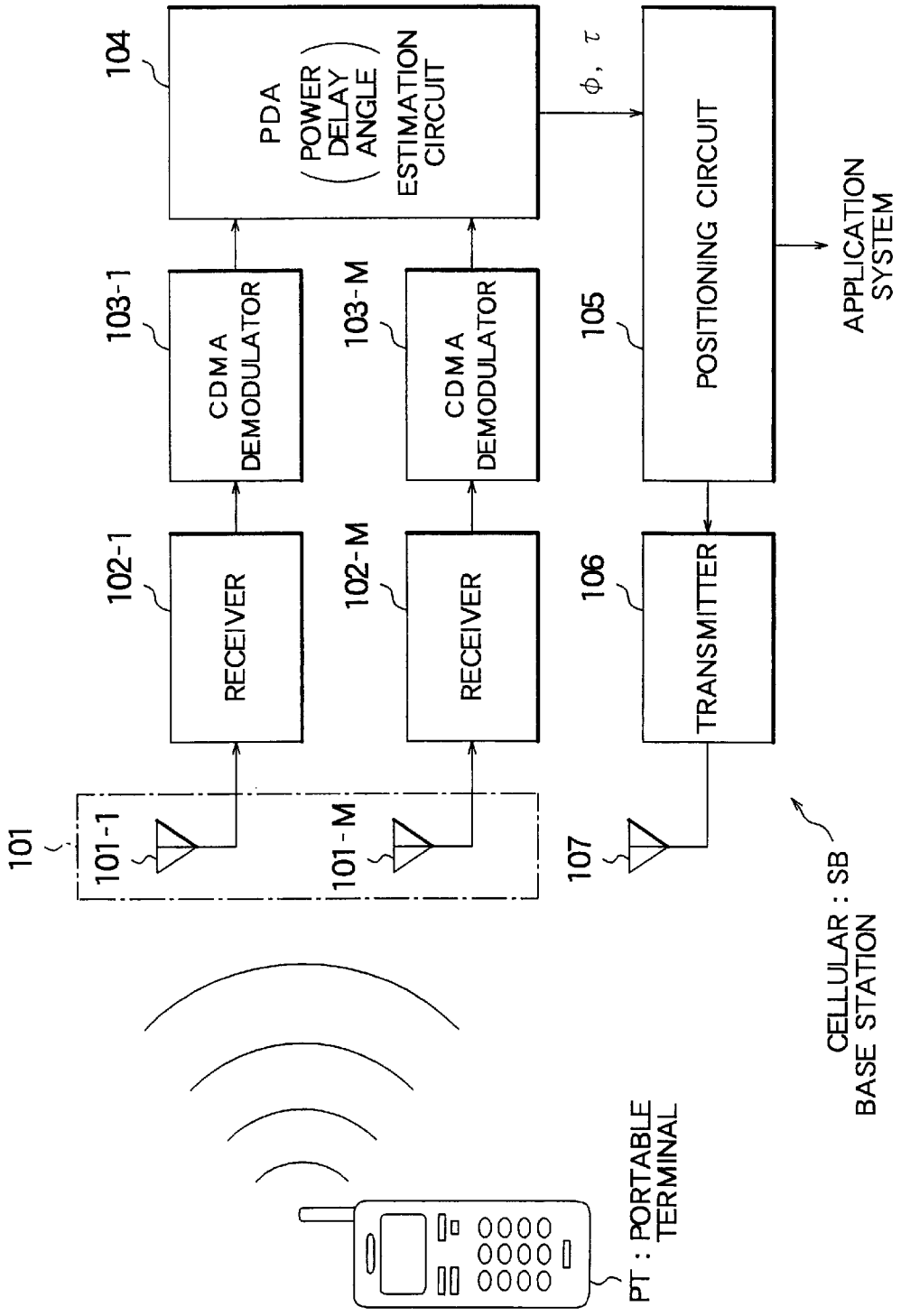

104
PDA (POWER DELAY ANGLE) ESTIMATION CIRCUIT
$\phi$, $\tau$
103-1
CDMA DEMODULATOR
103-M
CDMA DEMODULATOR
105
POSITIONING CIRCUIT
APPLICATION SYSTEM
102-1
RECEIVER
102-M
RECEIVER
106
TRANSMITTER
101
101-1
101-M
107
CELLULAR : SB
BASE STATION
PT : PORTABLE TERMINAL

FIG. 1

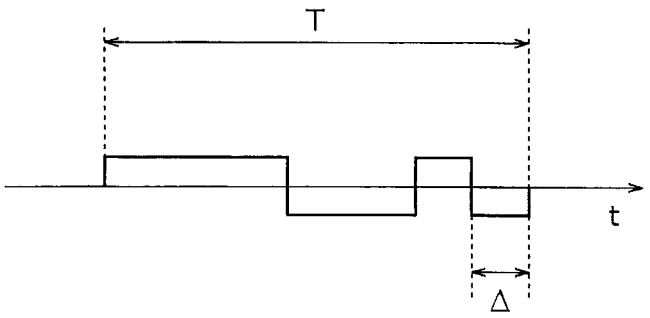



FIG. 2A

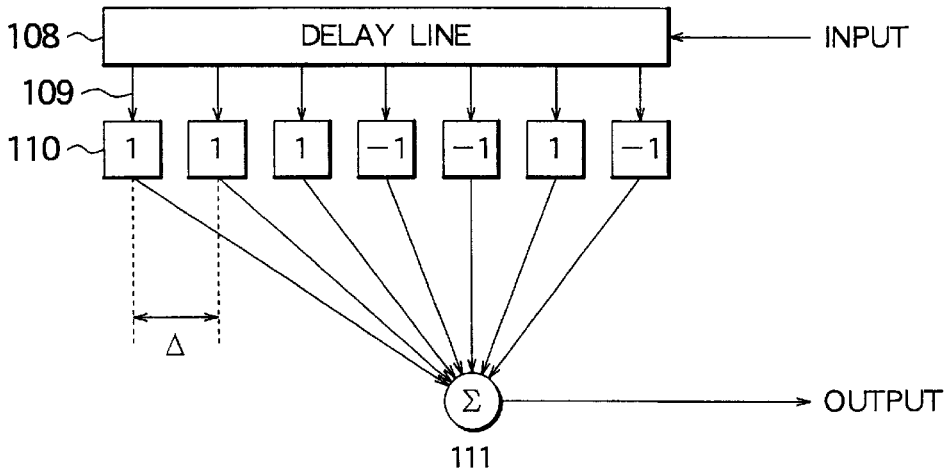



FIG. 2B

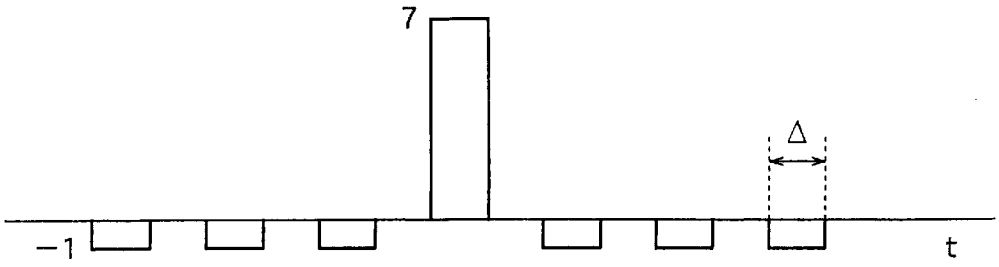



FIG. 2C

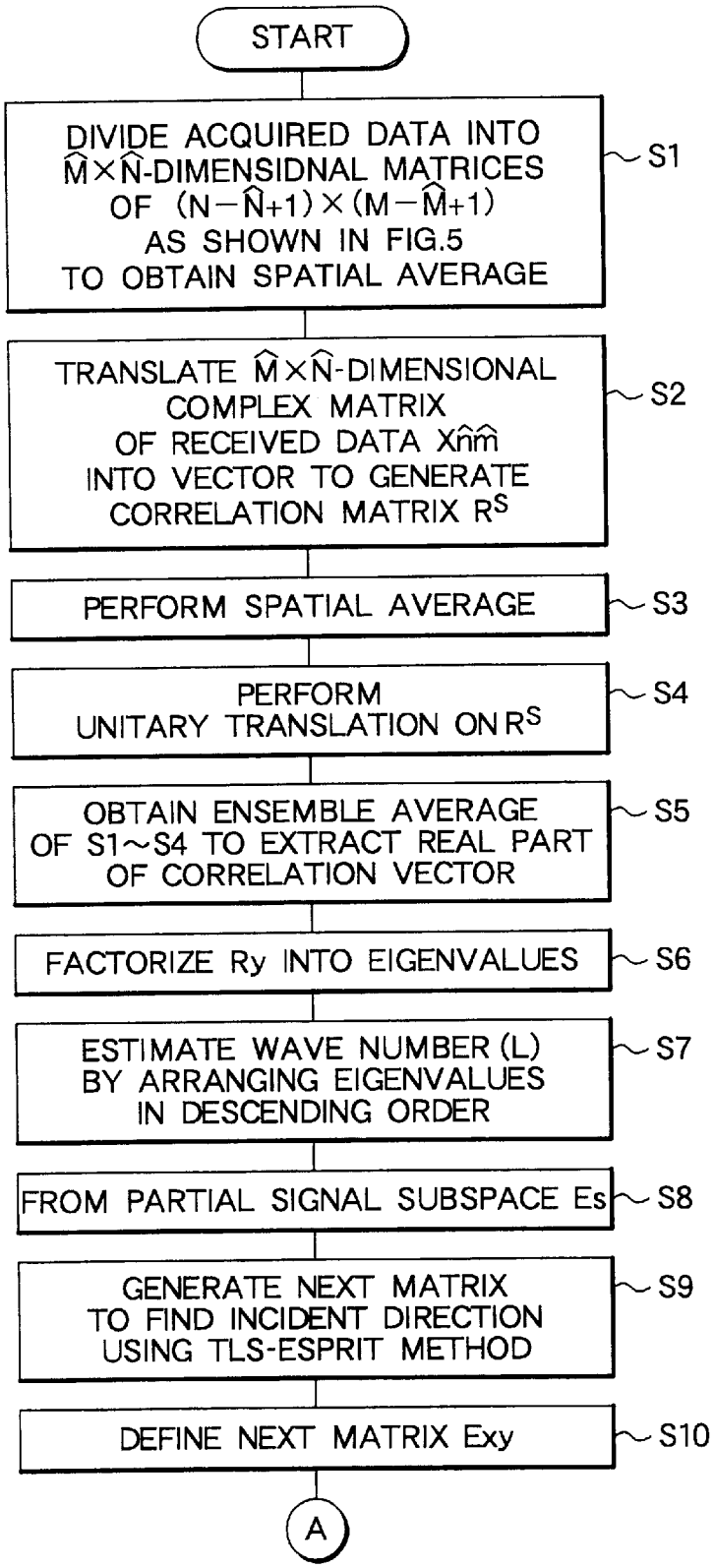

START
DIVIDE ACQUIRED DATA INTO $\hat{M}\times\hat{N}$-DIMENSIDNAL MATRICES OF $(N-\hat{N}+1)\times(M-\hat{M}+1)$ AS SHOWN IN FIG.5 TO OBTAIN SPATIAL AVERAGE
S1
TRANSLATE $\hat{M}\times\hat{N}$-DIMENSIONAL COMPLEX MATRIX OF RECEIVED DATA $X\hat{n}\hat{m}$ INTO VECTOR TO GENERATE CORRELATION MATRIX $R^S$
S2
PERFORM SPATIAL AVERAGE
S3
PERFORM UNITARY TRANSLATION ON $R^S$
S4
OBTAIN ENSEMBLE AVERAGE OF S1~S4 TO EXTRACT REAL PART OF CORRELATION VECTOR
S5
FACTORIZE Ry INTO EIGENVALUES
S6
ESTIMATE WAVE NUMBER (L) BY ARRANGING EIGENVALUES IN DESCENDING ORDER
S7
FROM PARTIAL SIGNAL SUBSPACE Es
S8
GENERATE NEXT MATRIX TO FIND INCIDENT DIRECTION USING TLS-ESPRIT METHOD
S9
DEFINE NEXT MATRIX Exy
S10
A

FIG. 3

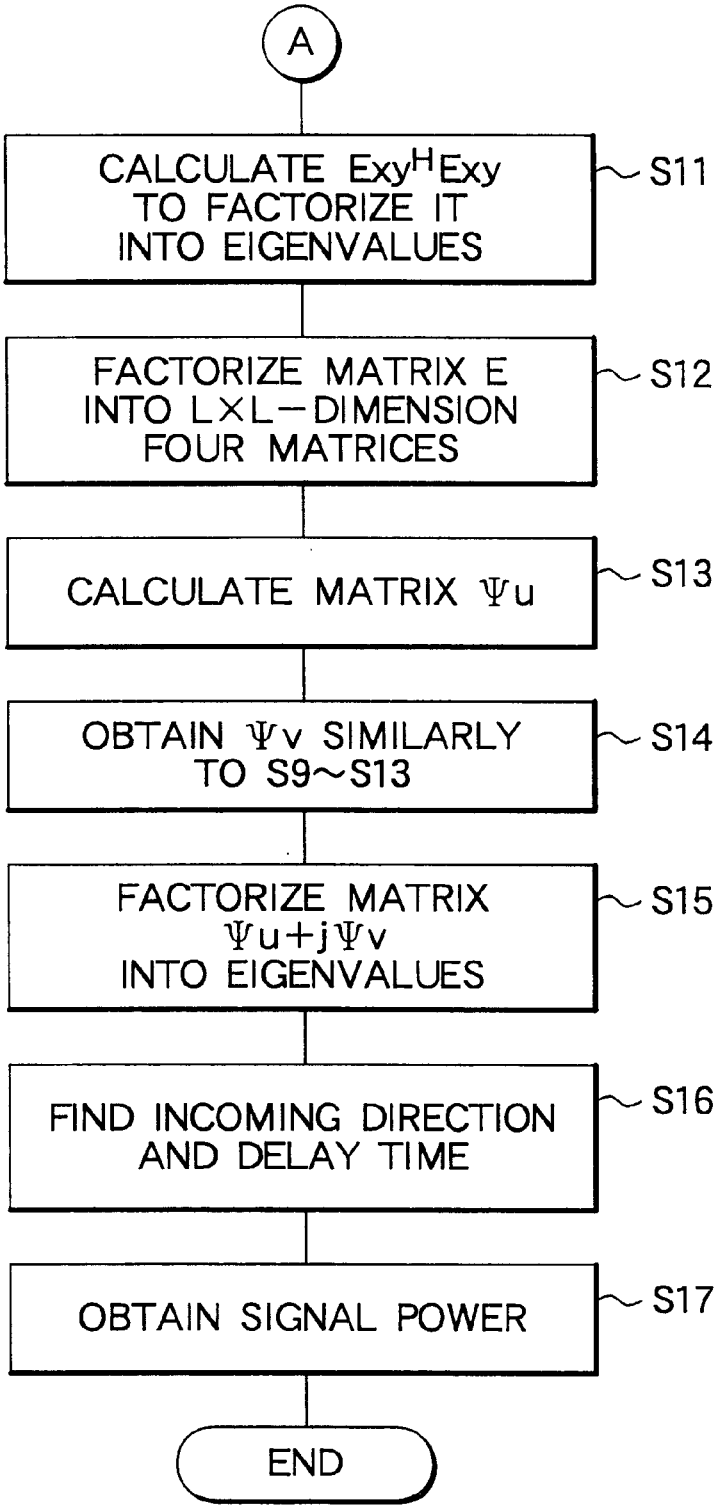

A
CALCULATE $Exy^{H}Exy$ TO FACTORIZE IT INTO EIGENVALUES
S11
FACTORIZE MATRIX E INTO L×L−DIMENSION FOUR MATRICES
S12
CALCULATE MATRIX Ψu
S13
OBTAIN Ψv SIMILARLY TO S9~S13
S14
FACTORIZE MATRIX Ψu+jΨv INTO EIGENVALUES
S15
FIND INCOMING DIRECTION AND DELAY TIME
S16
OBTAIN SIGNAL POWER
S17
END

FIG. 4

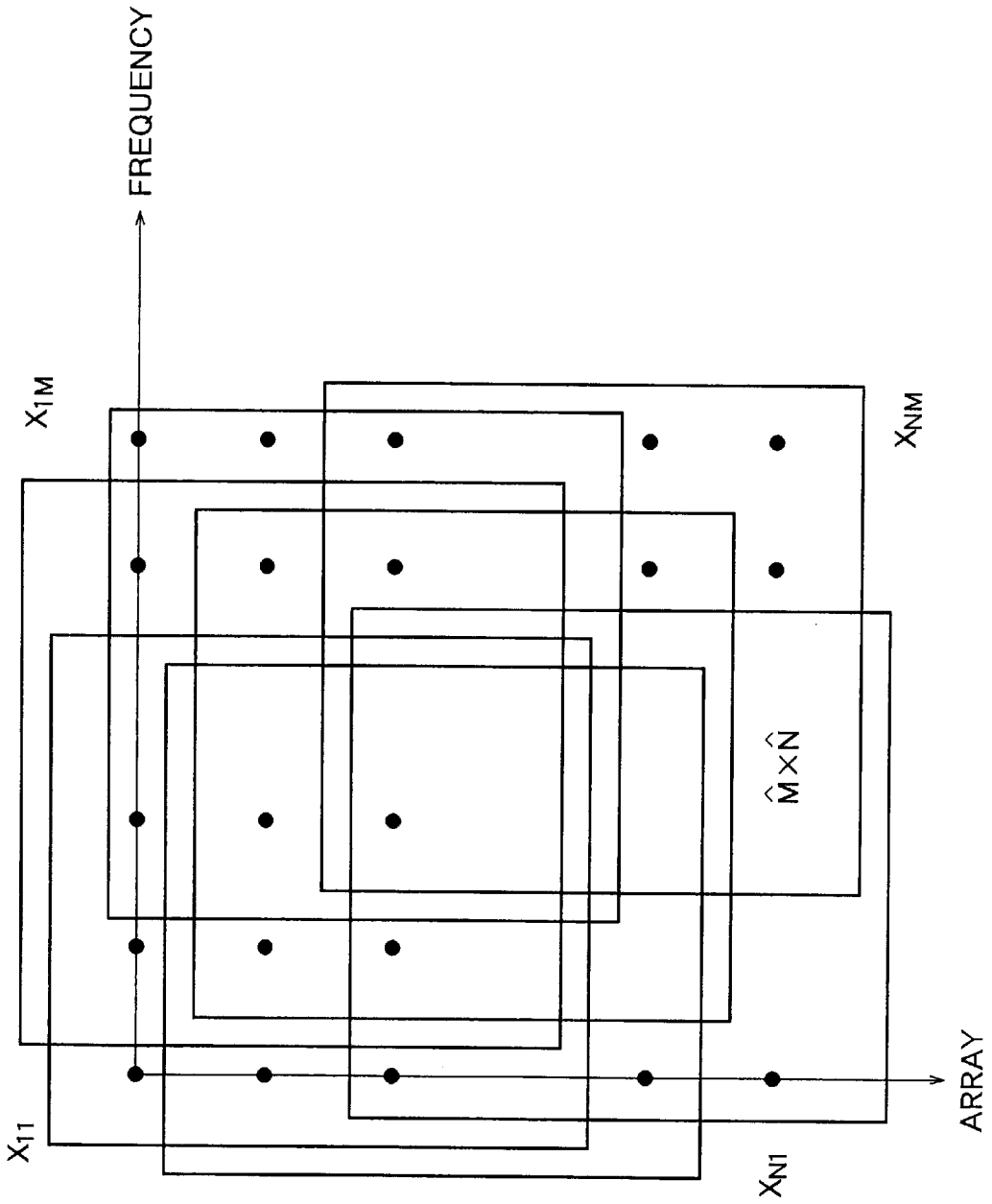



FIG. 5

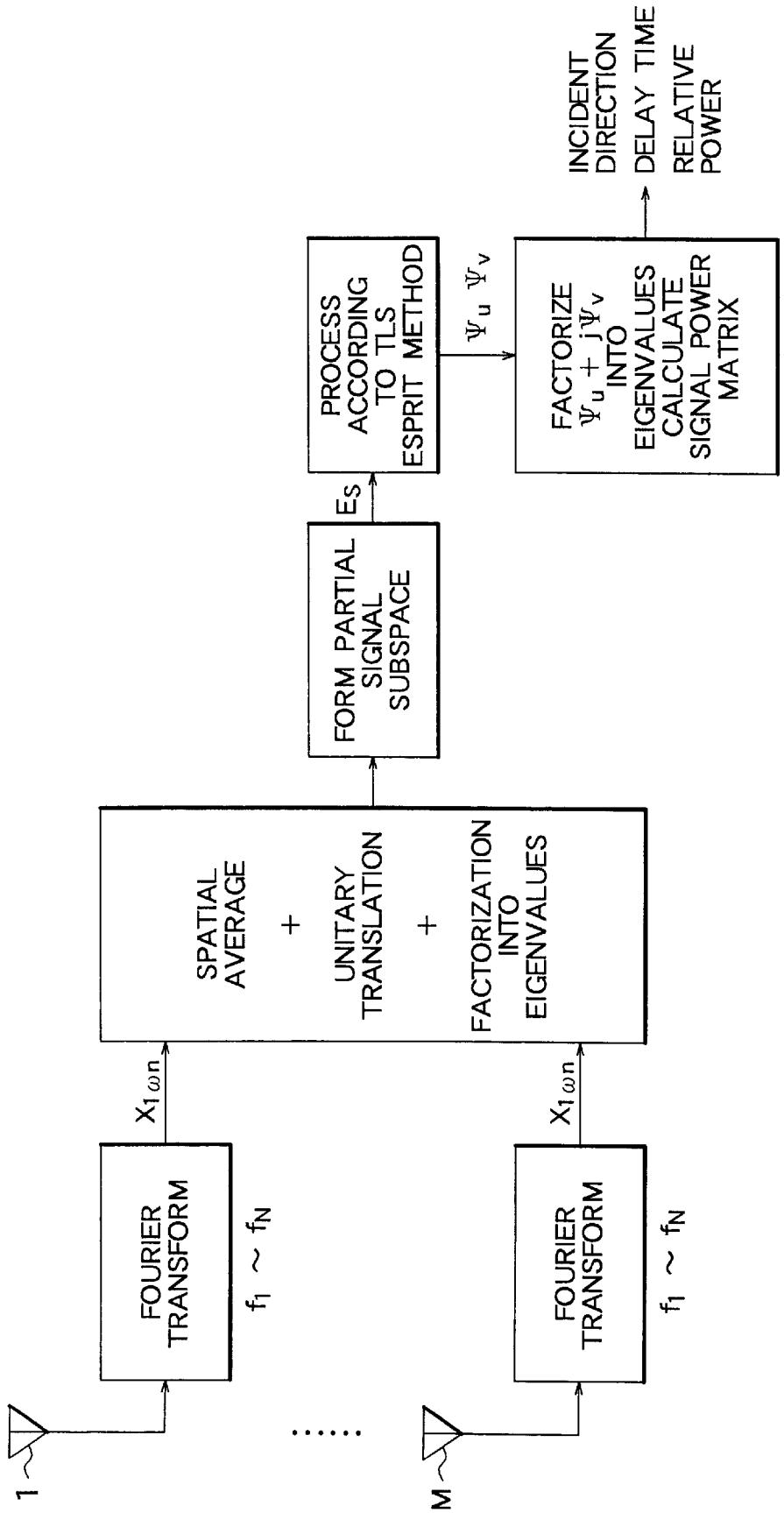

1
M
FOURIER TRANSFORM
FOURIER TRANSFORM
$f_1 \sim f_N$
$f_1 \sim f_N$
$X_{1\omega n}$
$X_{1\omega n}$
SPATIAL AVERAGE + UNITARY TRANSLATION + FACTORIZATION INTO EIGENVALUES
FORM PARTIAL SIGNAL SUBSPACE
$E_S$
PROCESS ACCORDING TO TLS ESPRIT METHOD
$\Psi_u$ $\Psi_v$
FACTORIZE $\Psi_u + j\Psi_v$ INTO EIGENVALUES CALCULATE SIGNAL POWER MATRIX
INCIDENT DIRECTION
DELAY TIME
RELATIVE POWER

FIG. 6

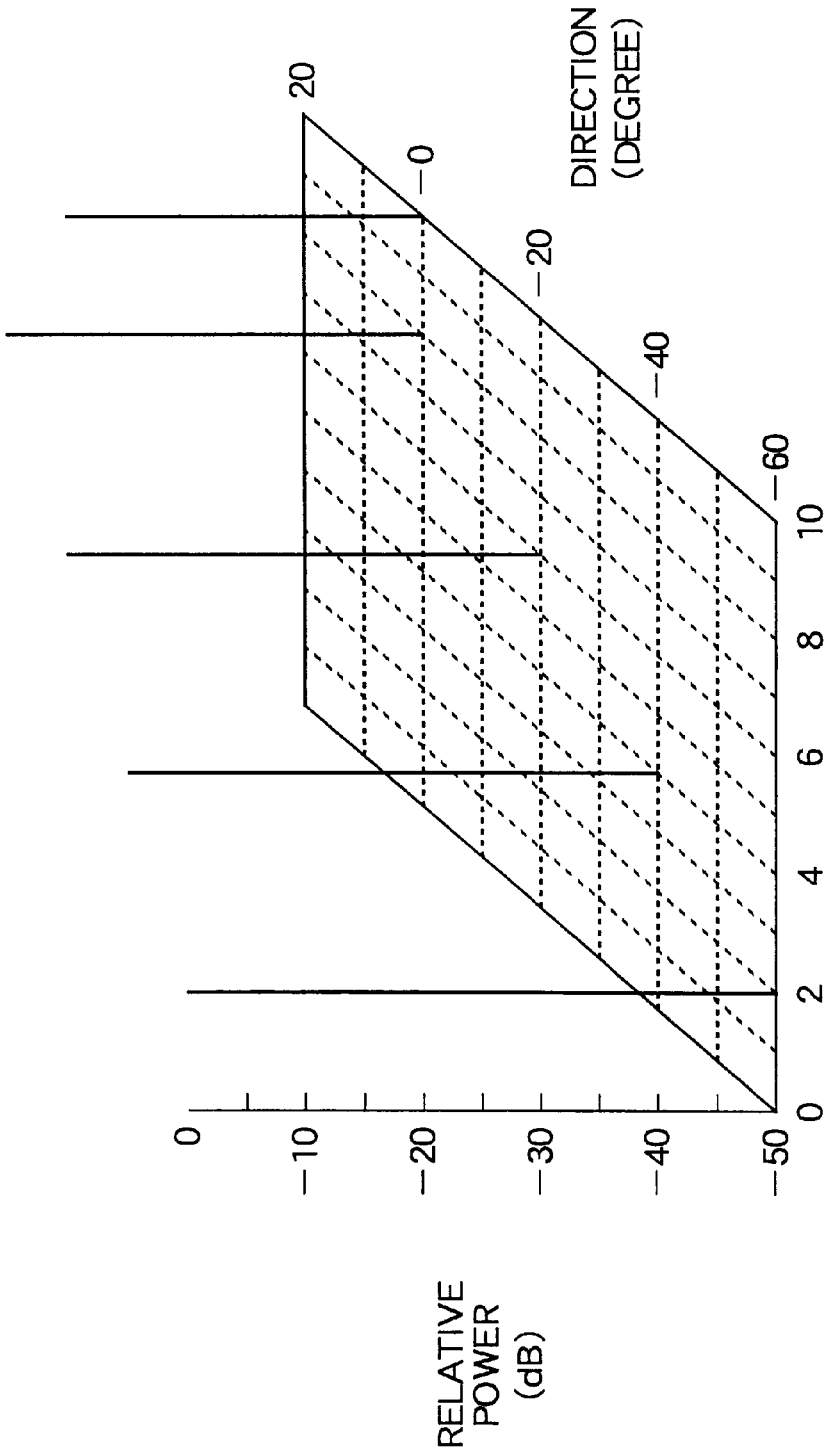

RELATIVE POWER (dB)
0
-10
-20
-30
-40
-50
DELAY TIME (μsec)
0
2
4
6
8
10
DIRECTION (DEGREE)
20
0
-20
-40
-60

FIG. 7

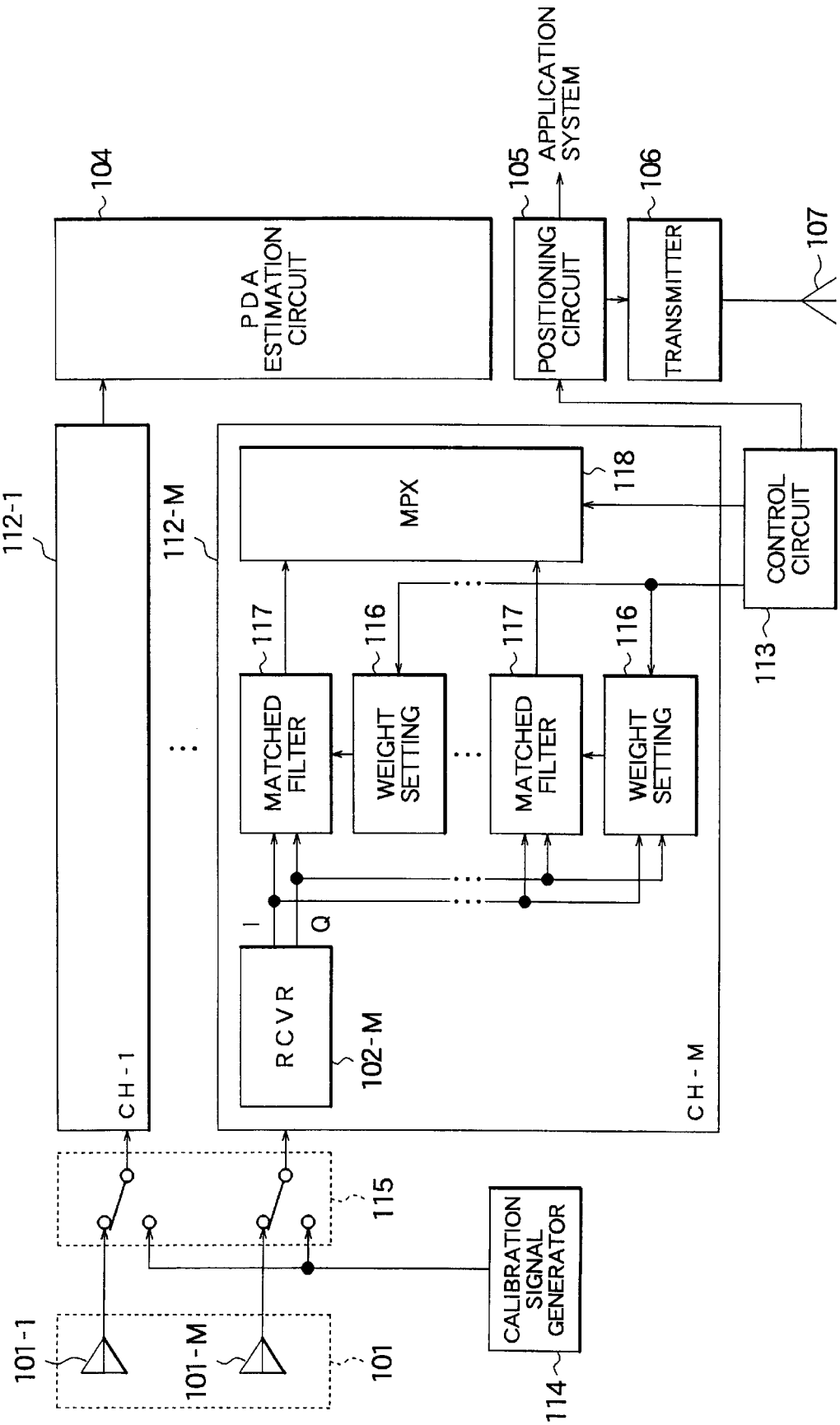

104
PDA ESTIMATION CIRCUIT
105
APPLICATION SYSTEM
POSITIONING CIRCUIT
106
TRANSMITTER
107
112-1
112-M
MPX
118
CONTROL CIRCUIT
113
117
116
MATCHED FILTER
WEIGHT SETTING
I
Q
RCVR
102-M
CH - 1
CH - M
115
CALIBRATION SIGNAL GENERATOR
114
101-1
101-M
101

FIG. 8

# POSITIONING APPARATUS USED IN A CELLULAR COMMUNICATION SYSTEM AND CAPABLE OF CARRYING OUT A POSITIONING WITH A HIGH ACCURACY IN URBAN AREA

## BACKGROUND OF THE INVENTION

This invention relates to a positioning apparatus (hereinafter a positioner) and more particularly to a positioner in a cellular base station that determines a position (positions) a portable terminal in a service area (cell) covered by the cellular base station.

Various methods of connection are employed in mobile communication systems such as portable telephone systems. Specifically, the methods of access can be generally classified into three methods, i.e., FDMA (frequency division multiple access) method, TDMA (time division multiple access) method and CDMA (code division multiple access) method. It has already been determined to use the CDMA method among those three methods for connection for IMT (international mobile telecommunication) 2000 which is the next generation portable telephone system because it employs a spread spectrum technique and therefore exhibits higher efficiency of frequency utilization compared to the TDMA method.

While there are many types of spread spectrum techniques (e.g., the direct spread (DS) method and frequency hopping (FH) method), this invention is applied to DS type spread spectrum communication (CDMA).

In such a CDMA type portable telephone system, it is desirable to position portable terminals. Such a need arises in consumer services and emergency car guiding systems. Consumer services are required by the IMT 2000 as an alternative to GPS navigation. Emergency call services are under evaluation and experiment in the United States as emergency car guiding systems.

Two methods described below have been used as systems for positioning portable terminals. One is a positioning system utilizing the GPS (global positioning system) method. In this positioning system, each portable terminal is equipped with a GPS receiver to allow the portable terminal to position itself, and the result of positioning at each portable terminal is transmitted to a base station to allow the base station to manage the information on the positions of the portable terminals.

The other is a positioning system utilizing a direction finder. In this positioning system, a plurality of base stations are provided with an azimuth detecting function, and a portable terminal is positioned based on a point at which azimuth lines defined by azimuth detection signals output by the base stations. The result of positioning may be transmitted from each base station to a portable terminal to allow its portable terminal to identify the position of itself.

However, the above-described positioning system utilizing the GPS method has problems as described below. The first problem is that it is subject to limitations during use in an urban area. The reason is that positioning requires reception signals from 3 or 4 CPS satellites, and it is difficult to identify locations that are blocked by buildings, roadside trees and the like. The second problem is that positioning accuracy is low. The reason is that positioning signals from GPS satellites open to public use are intentionally manipulated to provide low positioning accuracy in favor of the national interest of the United States.

The above-described positioning system utilizing a direction finder has problems as described below. The first problem is that it can not be used in existing cell configurations for portable telephones. The reason is that the positioning based on the output of a plurality of direction finders requires sufficient overlaps between the cells which does not currently exist. The second problem is that it is subject to limitations during use in an urban area. The reason is that it is necessary to maintain line of sight from several base stations to a portable terminal which is often difficult in an urban area.



## SUMMARY OF THE INVENTION

It is therefore an object of this invention to provide a positioning apparatus hardly affected in an urban area.

It is another object of this invention to provide a positioning apparatus capable of positioning portable terminals without changing cell configurations for portable telephones.

It is still another object of this invention to provide a positioning apparats capable of carrying out positioning with high accuracy.

On describing the gist of this invention, it is possible to understand that a positioning apparatus is provided in a cellular base station for positioning a portable terminal in a cell covered by the cellular base station. The positioning apparatus has a base portion indicative of a position of the cellular base station on a map.

According to this invention, the positioning apparatus comprises an array antenna for receiving a transmission signal transmitted by the portable terminal, receiver means for translating the reception signals into a plurality of baseband signals to demodulate the baseband signals into a plurality of demodulated signals, estimation means for estimating incident direction and delay time of the transmission signal on the basis of the demodulated signals to output an estimation result indicative of the incident direction and the delay time, and position calculating means for calculating a terminal position of the portable terminal on the map in accordance with the estimation result and the base position to output a terminal position signal indicative of the terminal position.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a cellular base station having a positioner according to a preferred embodiment of this invention along with a portable terminal.

FIGS. **2**A to **2**C show a principal of generation of a synchronous signal using matched filters provided in receivers of the cellular base station illustrated in FIG. **1**;

FIG. **3** is a flow chart of a first half of a procedure for estimating incident directions and delay times according to the 2D-Unitary ESPRIT method;

FIG. **4** is a flow chart of a second half of a procedure for estimating incident directions and delay times according to the 2D-Unitary ESPRIT method;

FIG. **5** is an illustration showing a method for spatial averaging according to the 2D-Unitary ESPRIT method;

FIG. **6** is a block diagram showing processing steps according to the 2D-Unitary ESPRIT method;

FIG. **7** is a graph showing an example of the result of PDA estimation carried out according to the 2D-Unitary ESPRIT method; and

FIG. **8** is a block diagram showing a configuration of a positioner illustrated in FIG. **1**.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**, the illustrated cellular base station SB comprises an array antenna **101** having first through M-th

antenna elements **101-1** through **101**-M for receiving signals transmitted by the portable terminal PT, where M represents a positive integer which is not less than one. First through M-th receivers **102-1** through **102**-M are for translating signals from the respective antenna elements of the array antenna **101** into baseband signals. First through M-th CDMA demodulators **103-1** through **103**-M are for demodulating a transmission signal multiplexed using the CMDA (code division multiple access) method to output demodulated signals in a plurality of systems. A PDA (power delay angle) estimation circuit **104** is for estimating an incident direction, delay time, and relative power from the demodulated signals in a plurality of systems and is for outputting the result of estimation indicating the incident direction, delay time, and relative power. A positioning circuit **105** is for establishing the position of the portable terminal PT on the basis of the incident direction and delay time indicated by the result of estimation output by the PDA estimation circuit **104** and is for outputting the result of position of the portable terminal PT. A transmitter **106** is for transmitting the result of positioning to the portable terminal PT through a transmission antenna **107**. The combination of the receivers and CDMA demodulators is referred to as receiving device. Among the above-described components, the transmitter **106** and transmission antenna **107** may be a transmitter and a transmission antenna shared by cellular base stations SB.

Reviewing FIG. **1**, the portable terminal PT transmits a spread spectrum signal which has been subjected to second order modulation using a predetermined second order modulation code. The cellular base station SB receives a multiplexed spread spectrum signal transmitted by a plurality of portable terminals PT in a service area (cell) covered by the cellular base station SB. As is well-known in this technical field, in order to demodulate a spread spectrum signal, it is necessary to capture the spread spectrum signal in synchronism therewith and to demodulate the synchronously captured spread spectrum signal using a second order modulation code assigned to the portable terminal PT.

Referring to FIGS. **2**A to **2**C, description will be made as regards synchronous capture carried out with a matched filter provided at each receiving device. FIG. **2**A indicates an input signal input to the matched filter. FIG. **2**B indicates the configuration of the matched filter. FIG. **2**C indicates an output signal output by the matched filter. As shown in FIG. **2**B, the matched filter comprises a delay line **108**, a plurality (seven in the illustrated example) of tape **109**, a plurality (seven in the illustrated example) of weighting circuits **110**, and an adder **111**.

Time sequence signals with a period T having codes corresponding to coefficients set in the seven weighting circuits **110** (1, 1, 1, −1, −1, 1, −1 in the example in FIG. **2**B) as shown FIG. **2**A are input to the matched filter. In this case, as shown in FIG. **2**C, auto-correlation is maximized to show a peak at timing when an input code agrees with a weighting code. Each of the CDMA demodulators **103-1** through **103**-M demodulates using such a peak as a synchronous pulse.

When the incident direction and delay time of a portable terminal PT is estimated from a plurality of demodulation signals received by the array antenna **101**, consideration must be paid on multi-path signals produced by reflection and diffraction due to buildings and the like especially in an urban environment. Specifically, it is necessary to select a direct wave from among a plurality of incident signals having correlation with each other and to find the incident direction and delay time of the same.

Description will be made on a method for estimating the incident direction and delay time of a plurality of correlated incident signals with reference to Hideo Kikuchi, Nobuyoshi Kijuma and Naoki Inagaki, "Simultaneous Estimation of the Incident Direction and Propagation Delay time of a Multiple Wave Using 2D-Unitary ESPRIT" Technical Report of IEICE, vol. 97–98, July 1997 (hereinafter referred to as article).

"2D-Unitary ESPRIT" is a method which was conceived to perform two-dimensional parameter estimation (direction/angular height, incident direction/delay time and the like) and which has the followings features.

(A) It requires no knowledge of the response (steering vector) of array elements at the antenna aperture.

(B) It does not require peak search based on the steering vector.

The relationship of rotational invariance in "2D-Unitary ESPRIT" is expressed by the following Equations (1) and (2).

$$\tan\left[\frac{\mu_i}{2}\right]K_{\mu 1}d(\mu_i, \nu_i) = K_{\mu 2}d(\mu_i, \nu_i) \tag{1}$$

$$\tan\left[\frac{\nu_i}{2}\right]K_{\nu 1}d(\mu_i, \nu_i) = K_{\nu 2}d(\mu_i, \nu_i) \tag{2}$$

The definitions for the parameters used here are as follows. $\mu 1$ and $\nu i$ are respectively expressed by Equations (3) and (4).

$$\mu_i = 2\pi f_0 \Delta d \sin\theta_i \tag{3}$$

$$\nu_i = -2\pi\Delta f\tau_i \tag{4}$$

The symbols in the above Equations (3) and (4) are given by:

f0: carrier frequency;

$\Delta$d: element interval;

$\theta$i: incident direction of an i-th incident wave;

$\Delta$f: frequency sweep interval;

$\tau$i: delay time of an i-th incident wave.

K$\mu$1 and K$\mu$2 in Equation (1) are expressed by Equation 6.

$$K_{\mu 1} = I_M \otimes K_1 \tag{6}$$

$$K_{\mu 2} = I_M \otimes K_2$$

where $\otimes$ represents a Kronecker operator.

K1 and K2 in the above Equation (6) are expressed by Equation (7).

$$K_1 = \mathrm{Re}[Q_{N-1}^H J_2 Q_N] \tag{7}$$

$$K_2 = \mathrm{Im}[Q_{N-1}^H J_2 Q_N]$$

where Re[·] represents a real part and Im[·] represents an imaginary part.

K$\nu$1 and K$\nu$2 in Equation (2) are expressed by Equation (8).

$$K_{\nu 1} = K_3 \otimes I_N \tag{6}$$

-continued

$$K_{v2} = K_4 \otimes I_N$$

K3 and K4 in the above Equation (8) are expressed by Equation (9).

$$K_3 = \mathrm{Re}[Q_{M\ 1}^{H} J_2 Q_M] \qquad (9)$$
$$K_4 = \mathrm{Im}[Q_{M-1}^{H} J_2 Q_M]$$

The suffixes M, N, IM, and IN in Equations (6) through (9) are given by:

M: The number of divisions of a frequency domain;

N: The number of array elements;

IM: M-dimensional order unit matrix;

IN: N-dimensional order unit matrix;

J2 in Equations (7) and (9) is expressed by Equation (11).

J2: selection matrix from the second through M(N)-th rows having the following format.

$$J_2 = \begin{bmatrix} 0 & 1 & & & 0 \\ 0 & & \ddots & & \\ \vdots & & & \ddots & \\ \vdots & & & & \ddots \\ 0 & 0 & & & 1 \end{bmatrix} \qquad (11)$$

QM or QN in Equations (7) and (9) represents an unitary matrix. When M(N) is an even number (M(N)=2K), the unitary matrix is given by:

$$Q_{2K} = \frac{1}{\sqrt{2}} \begin{bmatrix} I_K & jI_K \\ II_K & -jII_K \end{bmatrix} \qquad (12a)$$

When M(N) is an odd number (M(N)=2K+1), the unitary matrix is given by:

$$Q_{2K+1} = \frac{1}{\sqrt{2}} \begin{bmatrix} I_K & 0 & jI_K \\ o^T & \sqrt{2} & o^T \\ II_K & 0 & -jII_K \end{bmatrix} \qquad (12b)$$

where O, IK, T, and IIK in Equations 12a and 12b are as expressed by Equation (13).

$$II_K = \begin{bmatrix} & & & 1 \\ 0 & & \iddots & \\ & \iddots & & \\ \iddots & & & 0 \\ 1 & & & \end{bmatrix} \qquad (13)$$

where 0: 0 vector;

IK: K-dimensional unit matrix;

T: transpose of matrix.

Furthermore, d($\mu i$, $\nu i$) in Equations (1) and (2) is expressed by Equation (14).

$$d(\mu_i, \nu_i) = vec(D(\mu_i, \nu_i)) \qquad (14)$$

D($\mu i$, $\nu i$) in Equation (14) is expressed by Equation (15).

$$D(\mu_i, \nu_i) = d_N(\mu_i) d_M^{T}(\nu_i) \qquad (15)$$

$d_N(\mu i)$ and dM($\nu i$) in Equation 15 are respectively expressed by Equations (16) and (17).

$$d_N(\mu_i) = Q_N^{H} a_N(\mu_i) \qquad (16)$$

$$d_M(\nu_i) = Q_M^{H} a_M(\nu_i) \qquad (17)$$

aN($\mu i$) in Equation (16) and aM($\nu i$) in Equation (17) are respectively expressed by Equations (18) and (19).

$$a_N(\mu i) = \begin{bmatrix} \exp\{jN_1\mu_i\} \\ \vdots \\ \exp\{jN_N\mu_i\} \end{bmatrix} \qquad (18)$$

Equation (18) represents a steering vector of the incident direction.

$$a_M(\nu i) = \begin{bmatrix} \exp\{jM_1\nu_i\} \\ \vdots \\ \exp\{jM_M\nu_i\} \end{bmatrix} \qquad (19)$$

Equation (19) represents a steering vector of the delay time.

Mm ($1 \leqq m \leqq M$) in Equation (19) and Nn ($1 \leqq n \leqq N$) in Equation (18) are respectively expressed by Equations (20) and (21).

$$M_m = m - \frac{M+1}{2} \qquad (20)$$

$$N_n = n - \frac{N+1}{2} \qquad (21)$$

where vec(·) in Equation (14) is given by:

vec(·)=operator for translating an N×M-dimensional matrix into an NM-dimensional vector.

FIGS. **3** and **4** show a procedure for estimating incident direction and delay time according to "2D-Unitary ESPRIT" having the relationship of rotational invariance expressed by Equations (1) and (2).

Acquired data are divided into a matrix as shown in FIG. **5** in order to perform spatial averaging of the same (step **S1**).

The complex matrix of the received data is translated into a vector as expressed by Equation (23) to generate a correlation matrix $R^S$ as expressed by Equation (24) (step **S2**).

$$M_{\hat{n}\hat{m}} = vec(X_{\hat{n}\hat{m}}) \qquad (23)$$

$$R_{\hat{n}\hat{m}}^{S} = x_{\hat{n}\hat{m}} x_{\hat{n}\hat{m}}^{H} \qquad (24)$$

This operation is carried out for each subarray. Then, a spatial average process is carried out as expressed by Equation (25) (step **S3**).

$$R^S = \frac{1}{(N-\hat{N}+1)(M-\hat{M}+1)} \sum_{\hat{n}=1}^{N-\hat{N}+1} \sum_{\hat{m}=1}^{M-\hat{M}+1} R_{\hat{n}\hat{m}}^{S} \qquad (25)$$

The correlation matrix $R^S$ is subjected to unitary translation as expressed by Equation (26) (step **S4**).

$$Q^H_{\hat{M}\hat{N}} R^S Q_{\hat{M}\hat{N}} \quad (26)$$

$$Q^H_{\hat{M}\hat{N}} - Q^H_{\hat{M}} \otimes Q^H_{\hat{N}}$$

$$Q_{\hat{M}\hat{N}} - Q_{\hat{M}} \otimes Q_{\hat{N}}$$

where ⊗ represents a Kronecker operator.

Subsequently, the real part of the correlation matrix is extracted by performing ensemble averaging of steps **S1** through **S4** as expressed by Equation (27) (step **S5**).

$$Ry = \mathrm{Re}[E[Q^H_{\hat{M}\hat{N}} R^S Q_{\hat{M}\hat{N}}]] \quad (27)$$

Ry is factorized into eigenvalues (step **S6**) in order to obtain results defined by:

λi: eigenvalue (i=1, . . . N̂M̂)

ei: eigen-vector corresponding to λi

The eigenvalues are arranged in a descending order to estimate a wave number (L) as expressed by Equation (29) (step **S7**).

$$\lambda_1 \geqq \lambda_2 \geqq \ldots \geqq \lambda_L > \lambda_{L+1} = \ldots = \lambda_{\hat{M}\hat{N}} = \sigma^2 \quad (29)$$

A signal subspace $E_S$ as expressed by Equation (30) is formed (step **S8**).

$$E_s = [e_1\ e_2, \ldots, e_L] \quad (30)$$

A next matrix E $\mu$ as expressed by Equation (31) is generated to find the incident direction in accordance with the TLS-ESPRIT method (step **S9**).

$$E_\mu = \begin{bmatrix} K_{\mu 1} & E_S \\ K_{\mu 2} & E_S \end{bmatrix} \quad (31)$$

First, a next matrix $E_{XY}$ as expressed by Equation (32) is defined (step **310**).

$$E_{XY} = [K_{\mu 1} E_S \mid K_{\mu 2} E_S] \quad (32)$$

Next, $E_{XY}{}^H E_{XY}$ expressed by Equation (33) is calculated to factorize it into eigenvalues (step **S11**).

$$E^H_{XY} E_{XY} = \begin{bmatrix} (K_{\mu 1} E_S)^H \\ (K_{\mu 2} E_S)^H \end{bmatrix} [K_{\mu 1} E_S \mid K_{\mu 2} E_S] = E \Lambda E \quad (33)$$

where Λ=diag[λ1, λ2, . . . λ2L], λi represents eigenvalues (λ1≧, . . . ≧λ2L), E=(e1 |e2 | . . . |$e_{2L}$), and ei represents eigen-vector corresponding to i

The matrix E is factorized into four L×L-dimensional matrices as expressed by Equation (34) (step **S12**).

$$E = \left[\begin{array}{c|c} E_{11} & E_{12} \\ \hline E_{21} & E_{22} \end{array}\right] \quad (34)$$

Then, a matrix $\Psi\mu$ as expressed by Equation (35) is calculated (step **S13**).

$$\Psi_\mu = -E_{12}[E_{22}]^{-1} \quad (35)$$

A matrix Ψν is calculated in a manner similar to steps **S9** to **S13** (step **S14**). A matrix E is expressed by Equation (36).

$$E_v = \begin{bmatrix} K_{v1} & E_S \\ K_{v2} & E_S \end{bmatrix} \quad (36)$$

Subsequently, a matrix (Ψμ+jΨν) is factorized into eigenvalues as expressed by Equation (37) (step **S15**).

$$\{\Psi_\mu + j\Psi_v\} = T^{-1}\{\Omega_\mu + j\Omega_v\}T \quad (37)$$

where a term wμ(i)+jwν(i) diagonal to (Ψμ+Ψνj) becomes the eigenvalue (i=1, . . . , L). Furthermore, L column vectors of $T^{-1}$ are eigen-vectors.

At step **S16**, the incident direction is given by:

$$\mu_i = 2\pi f_0 \Delta d \sin\theta_i = 2\tan^{-1} w_\mu(i) \quad (38)$$

$$\theta_i = \sin^{-1}\left\{\frac{\tan^{-1} w_\mu(i)}{\pi f_0 \Delta d}\right\}$$

At the step **S16**, the delay time is given by:

$$v_i = -2\pi\Lambda f t_i = 2\tan^{-1} wv(i) \quad (39)$$

$$\tau_i = \frac{\tan^{-1} wv(i)}{\pi\Delta f}$$

Finally, the signal power is calculated (step **S17**). The Matrix for the signal power is expressed by Equation (40).

$$\overline{P} = T[\Lambda_S - \sigma^2 I_L]T^H \quad (40)$$

where ΛS is given by Equation (41) and $I_L$ is an L×L-dimensional unit matrix.

$$\Lambda_S = diag[\lambda_1 \lambda_2, \ldots, \lambda_L] \quad (41)$$

where ΛS represents eigenvalues for a signal.

A component diagonal to P is the signal power.

FIG. **6** shows the above-described processing steps according to the "2D-Unitary ESPRIT" method in the form of a simple block diagram. In FIG. **6**, each of signals received by M antennas is subjected to Fourier transform and is supplied to a block for spatial average, unitary translation, and factorization into eigenvalues. The block for spatial average, unitary translation, and factorization into eigenvalues is a block that performs the processes at steps **S1** to **S6** in FIG. **3**. The output of the block for spatial average, unitary translation, and factorization into eigenvalues is supplied to a block for forming a partial signal subspace which performs the processes at steps **S7** and **S9** in FIG. **3**. The output of the block for forming a partial signal subspace is supplied to a block for processing according to the TLS ESPRIT method which performs the processes at steps **S9** through **S14** in FIG. **3**. Matrixes Ψμ and Ψν outputted from the block for processing according to the TLS ESPRIT method are supplied to a block for factorizing Ψμ+jΨν into eigenvalues, signal power, and matrix calculation where. By this block, the processes at steps **S15** through **S17** in FIG. **3** are performed to output the incident direction, delay time and relative power.

FIG. **7** shows examples of the delay time, incident direction, and relative power of reception signals propagated

in a multiplex manner from one portable terminal PT and arriving at the base station SB according to the "2D-Unitary ESPRIT" method. The examples in FIG. **7** are examples of five reception signals propagated in a multiplex manner. The five reception signals are referred here as first through fifth reception signals which have respective increasing delay times.

The first reception signal is a signal with a delay time of $2\mu$ seconds in an incident direction of −60 degrees. The second reception signal is a signal with a delay time of $4\mu$ seconds in an incident direction of −40 degrees. The third reception signal is a signal with a delay time of $6\mu$ seconds in an incident direction of 20 degrees. The fourth reception signal is a signal with a delay time of $8\mu$ seconds in an incident direction of 0 degree. The fifth reception signal is a signal with a delay time of $10\mu$ seconds in an incident direction of 0 degree.

In the example shown in FIG. **7**, the positioning circuit **105** determines the first reception signal in an incident direction of −60 degrees which arrives first as a direct wave and judges that the distance between the portable terminal PT and the cellular base section SB is 600 meters from the delay time of $2\mu$ seconds. The result of estimation of the incident direction and delay time is sent to an application system and also transmitted to the portable terminal PT as needed.

Referring to FIG. **8**, description will be made as regards an example of the positioner. In FIG. **8**, Parts having the same functions as those in FIG. **1** are indicated by like reference numbers. The illustrated positioner comprises an array antenna **101**, a PDA estimation circuit **104**, a positioning circuit **105**, a transmitter **106**, a transmission antenna **107**, first through M-th receiving devices **112-1** to **112**-M, a control circuit **113**, a calibration signal generator **114** and a calibration signal switch **115**.

The array antenna **101** is formed by first through M-th antenna elements **101-1** to **101**-M. The array antenna **101** receives signals transmitted by a plurality of portable terminals and outputs them to the first through M-th receiving devices **112-1** to **112**-M through the calibration signal switch **115**. Since the first through M-th receiving devices **112-1** to **112**-M have the same configuration, only the M-th receiving device **112**-M is illustrated here. The M-th receiving device **112**-M comprises a receiver (RCVR) **102**-M, a plurality of weight setting circuits **116**, a plurality of matched filters **117** and a multiplexer circuit (MPX) **118**.

The receiver **102**-M translates a signal received by the M-th antenna element **101**-M into a base band signal and phase detects to output an IQ-separated signal to the matched filters **117**. The matched filters **117** and the weight setting circuit **116** are prepared in quantities corresponding to the expected maximum number of portable terminals. Weights associated with a demodulation code for each portable terminal are set by the control circuit **113** in the weight setting circuits **116**, and the IQ-separated signal is demodulated by the matched filters **117**. Demodulated outputs corresponding to the number of portable terminals are multiplexed in time domain at the multiplexer circuit **118** and transmitted to the PDA estimation circuit **104**. That is, the combination of the plurality of weight setting circuits **116**, the plurality of matched filters **117** and the multiplexer circuit **118** corresponds to one CDMA demodulator shown in FIG. **1**.

The control circuit **113** sends the information of weights to the weight setting circuit **116** depending on the number of access from the portable terminals and controls the multiplexer circuit **118** to cause it to output demodulated signals in respective systems simultaneously at preset timing.

The FDA estimation circuit **104** uses the above-described "2D-Unitary ESPRIT" method to estimate the delay time and incident direction of each portable terminal and transmits the result of estimation to the positioning circuit **105**. The positioning circuit **105** finds the positions of the portable terminals relative to the base station on the basis of the information indicative of the delay time and incident direction of each portable terminal. The positioning circuit **105** supplies the application system and the transmitter **106** relative position information indicating such relative positions along with the information of the absolute position of the base station. The transmitter **106** multiplexes the information on the position of each portable terminal according to the CDMA method and transmits it to each portable terminal through an aerial by transmitting antenna **107**.

The calibration signal generator **114** generates a calibration signal for calibrating the channel gain between the receiving systems and errors in the transmission phase throughout the frequency band. When calibration is carried out, the setting of the calibration signal switch **115** is changed in order to supply the calibration signal to the first through M-th receiving devices **112-1** to **112**-M.

The embodiment having such a configuration makes it possible to position a plurality of portable terminals (mobile terminals) in a cell with a device in only one base station covering the cell. The result of positioning may be displayed on the mobile terminals to provide services that replace the existing GPS. The result of positioning may be transmitted to service systems at relevant organizations to allow various services, e.g., guidance of emergency vehicles.

Above-cited article A show that the accuracy of incident direction estimation is 0.5 degrees and the accuracy of delay time estimation is 0.1 nanosecond when there are two incident waves in directions different from each other by 25 degrees with a difference of 5 nanoseconds in delay time. For current cells for portable telephones which have a radius of about 1 Km, the accuracy of positioning is dominated by direction and is about 9 meters which is a preferable value compared to the accuracy of the positioning 20 to 200 meters of GPS.

As readily understood from the above-mentioned description, the direct wave and the multipath wave are separately identified so that the portable terminal is positioned on the base of the incident direction and delay time of the direct wave. Therefore, it is possible to prevent the position service of the portable terminal from limitation in an urban area.

Since the cellular base station estimates not only incident directions but also delay times, it is possible to use a cell configuration for portable telephones.

Furthermore, it is possible to provide the positioning service with a high accuracy inasmuch as no intentional manipulation is made to reduce accuracy in favor of the national interest of one country unlike the case of GPS.

While this invention has thus far been described in conjunction with the preferred embodiment thereof, it will readily be possible for those skilled in the art to put this invention into practice in various other manners.

What is claimed is:

**1**. A positioning apparatus provided in a cellular base station for determining a position of a portable terminal in a cell covered by said cellular base station, said positioning apparatus having a base position indicative of a position of said cellular base station on a map, the positioning apparatus comprising:

an array antenna for receiving a transmission signal transmitted by said portable terminal to output a plurality of reception signals;

receiver means for translating said reception signals into a plurality of baseband signals to demodulate said baseband signals into a plurality of demodulated signals;

estimation means for estimating incident direction and delay time of said transmission signal on the basis of said demodulated signals to output an estimation result indicative of said incident direction and said delay time; and

position calculating means for calculating a terminal position of said portable terminal on said map in accordance with said estimation result and said base position to output a terminal position signal indicative of said terminal position.

**2**. A positioning apparatus as claimed in claim **1**, wherein:

said portable terminal comprises transmitting means for transmitting a multiplexed spread spectrum signal as said transmission signal; and

said receiver means comprising a plurality of receivers each of which has a plurality of matched filters for separately demodulating said multiplexed spread spectrum signals.

**3**. A positioning apparatus as claimed in claim **1**, wherein said estimation means comprises:

first means for translating said demodulated signals to digital signals;

second means for estimating the incident direction and the delay time of said transmission signal in accordance with 2D Unitary ESPRIT fashion, said second means further estimating a relative power of said transmission signal in accordance with 2D Unitary ESPRIT; and

third means for outputting said estimation result having said relative power together with said incident direction and said delay time.

**4**. A positioning apparatus as claimed in claim **1**, wherein said position calculating means comprises:

first means for determining an incident signal having a shortest delay time as a direct wave on the basis of said estimation result; and

second means for calculating said portable position on the basis of said direct wave and the said base position.

**5**. A positioning apparatus as claimed in claim **1**, further comprising:

transmitter means for transmitting said portable position signal as a position transmission signal; and

an antenna for emitting the said position transmission signal into a subspace.

**6**. A positioning apparatus as claimed in claim **5**, wherein said transmitter means produces a multiplexed signal having said position transmission signal.

**7**. A cellular base station communicating with a portable terminal located in a cell, wherein said cellular base station comprises:

positioning means for determining a position of said portable terminal in the cell covered said cellular base station; and

transmission means for transmitting said determined position as a position signal to said portable terminal.

**8**. A cellular base station communicating with a portable terminal located in a cell, said portable terminal transmitting a spread spectrum signal on communicating with said cellular base station, said cellular base station comprising a positioning apparatus for determining a position of said portable terminal, wherein said positioning apparatus comprises:

receiver means for receiving said spread spectrum signal as a reception signal;

estimating means for estimating an incident direction and a delay time of said reception signal on the basis of said reception signal to output an estimation result indicative of said incident direction and said delay time; and

calculating means for calculating the position of said portable terminal in accordance with said estimation result.

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