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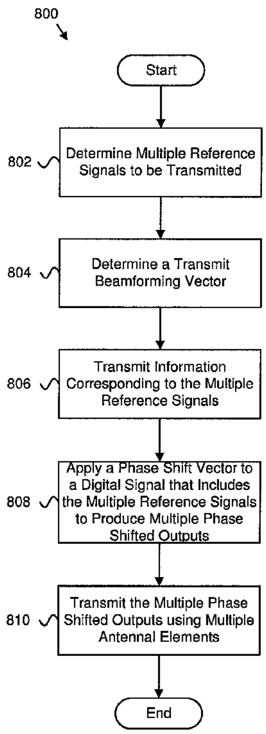

FIG. 8

(57) Abstract: Apparatuses, methods, and systems are disclosed for channel coefficient estimation. One apparatus includes an antenna array having multiple antenna elements. The apparatus also includes a phase shifter that applies a phase shift vector to a digital signal that includes multiple reference signals to produce multiple phase shifted outputs. The apparatus includes a transmitter that transmits the multiple phase shifted outputs via the multiple antenna elements. Each antenna element of the multiple antenna elements transmits a respective phase shifted output of the multiple phase shifted outputs.

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APPARATUSES AND METHODS FOR CHANNEL COEFFICIENT ESTIMATION

FIELD

[0001] The subject matter disclosed herein relates generally to wireless communication systems and more particularly relates to apparatuses and methods for channel coefficient estimation in a wireless communication system.

BACKGROUND

[0002] The following abbreviations are herewith defined, at least some of which are referred to within the following description.

[0003] 3GPP Third Generation Partnership Project

[0004] ACK Positive-Acknowledgment

[0005] ANDSF Access Network Discovery and Selection Function

[0006] AP Access Point

[0007] APN Access Point Name

[0008] BLER Block Error Ratio

[0009] BPSK Binary Phase Shift Keying

[0010] CAZAC Constant Amplitude Zero Auto Correction

[0011] CCA Clear Channel Assessment

[0012] CCE Control Channel Element

[0013] CP Cyclic Prefix

[0014] CQI Channel Quality Indicator

[0015] CSI Channel State Information

[0016] CSI-RS Channel State Information Reference Signal

[0017] CSS Common Search Space

[0018] DCI Downlink Control Information

[0019] DL Downlink

[0020] eNB Evolved Node B

[0021] EPDCCH Enhanced Physical Downlink Control Channel

[0022] E-RAB E-UTRAN Radio Access Bearer

[0023] ETSI European Telecommunications Standards Institute

[0024] E-UTRAN Evolved Universal Terrestrial Radio Access Network

[0025] FBE Frame Based Equipment

[0026] FDD Frequency Division Duplex

[0027] FDMA Frequency Division Multiple Access

[0028] FEC Forward Error Correction

[0029] FFT Fast Fourier Transform

[0030] GPRS General Packet Radio Service

[0031] GPT GPRS Tunneling Protocol

[0032] HARQ Hybrid Automatic Repeat Request

[0033] H-PLMN Home Public Land Mobile Network

[0034] IFFT Inverse FFT

[0035] IP Internet Protocol

[0036] ISRP Inter-System Routing Policy

[0037] LAA Licensed Assisted Access

[0038] LBE Load Based Equipment

[0039] LBT Listen-Before-Talk

[0040] LTE Long Term Evolution

[0041] MCL Minimum Coupling Loss

[0042] MCS Modulation and Coding Scheme

[0043] MIMO Multiple-Input, Multiple-Output

[0044] mmW Millimeter Wave

[0045] MME Mobility Management Entity

[0046] MMSE Minimum Mean Square Error

[0047] MRC Maximal-Ratio Combining

[0048] MU-MIMO Multi-User, Multiple-Input, Multiple-Output

[0049] NACK or NAK Negative-Acknowledgment

[0050] NAS Non-Access Stratum

[0051] NBIFOM Network-Based IP Flow Mobility

[0052] OCC Orthogonal Cover Code

[0053] OFDM Orthogonal Frequency Division Multiplexing

[0054] PCell Primary Cell

[0055] PBCH Physical Broadcast Channel

[0056] PCO Protocol Configuration Options

[0057] PCRF Policy and Charging Rules Function

[0058] PDCCH Physical Downlink Control Channel

[0059] PDCP Packet Data Convergence Protocol

[0060] PDN Packet Data Network

[0061] PDSCH Physical Downlink Shared Channel

[0062] PDU Protocol Data Unit

[0063] PGW Packet Data Network Gateway

[0064] PHICH Physical Hybrid ARQ Indicator Channel

[0065] PLMN Public Land Mobile Network

[0066] PMI Precoding Matrix Indicator

[0067] PRACH Physical Random Access Channel

[0068] PRB Physical Resource Block

[0069] PTI Procedure Transaction Identity

[0070] PUCCH Physical Uplink Control Channel

[0071] PUSCH Physical Uplink Shared Channel

[0072] QoS Quality of Service

[0073] QPSK Quadrature Phase Shift Keying

[0074] RAB Radio Access Bearer

[0075] RAN Radio Access Network

[0076] RAR Random Access Response

[0077] RI Rank Indicator

[0078] RRC Radio Resource Control

[0079] RS Reference Signal

[0080] RX Receive

[0081] SC-FDMA Single Carrier Frequency Division Multiple Access

[0082] SCell Secondary Cell

[0083] SCH Shared Channel

[0084] SGW Serving Gateway

[0085] SIB System Information Block

[0086] SINR Signal-to-Interference-Plus-Noise Ratio

[0087] SNR Signal-to-Noise Ratio

[0088] SR Scheduling Request

[0089] SRS Sounding Reference Signal

[0090] TAU Tracking Area Update

[0091] TB Transport Block

[0092] TBS Transport Block Size

[0093] TCP Transmission Control Protocol

[0094] TDD Time-Division Duplex

[0095] TDM Time Division Multiplex

[0096] TEID Tunnel Endpoint Identification ("ID")

[0097] TX Transmit

[0098] UCI Uplink Control Information

[0099] UE User Entity/Equipment (Mobile Terminal)

[00100] UL Uplink

[00101] UMTS Universal Mobile Telecommunications System

[00102] V-PLMN Visited Public Land Mobile Network

[00103] WiMAX Worldwide Interoperability for Microwave Access

[00104] WLAN Wireless Local Area Network

[00105] ZF Zero Forcing

[00106] In wireless communications networks, higher network capacity may be desired. Accordingly, millimeter wave communications systems may be used. Millimeter wave ("mmW") may have a large amount of available contiguous bandwidth with a shorter wavelength (e.g., 1 mm to 10 mm) than often used in wireless communication networks and may have unique channel properties. Compared with microwave, mmW propagation may exhibit less diffraction and more reflection, resulting in more directional transmission. Moreover, mmW propagation may have larger path loss than microwave thereby making it suitable for use with a small transmission radius (e.g., 100 m to 200 m). In some configurations, mmW propagation may be used as a wireless backhaul technique.

[00107] Certain mmW communication systems may use large scale antenna arrays and a MIMO technique. For example, because of the shorter wavelength of mmW, a large number of antenna elements may be packed into a small area. In one configuration, an eNB may have 64, 128, 1024, or more antenna elements. In another configuration, a UE may have 16, 32, or more antenna elements. It may be difficult to determine channel coefficients for each antenna element in such a system.

BRIEF SUMMARY

[00108] Apparatuses for channel coefficient estimation are disclosed. Methods and systems also perform the functions of the apparatus. In one embodiment, the apparatus includes an antenna array having multiple antenna elements. In various embodiments, the apparatus includes a phase shifter that applies a phase shift vector to a digital signal that includes multiple reference signals to produce multiple phase shifted outputs. In certain embodiments, the apparatus includes a transmitter that transmits the multiple phase shifted outputs via the

multiple antenna elements. In such embodiments, each antenna element of the multiple antenna elements transmits a respective phase shifted output of the multiple phase shifted outputs.

[00109] In certain embodiments, a number of reference signals of the multiple reference signals is at least equal to a number of antenna elements of the multiple antenna elements that transmit the multiple reference signals. In another embodiment, the transmitter transmits the multiple phase shifted outputs via a millimeter wave frequency in a time-frequency domain using orthogonal frequency-division multiplexing ("OFDM"). In some embodiments, the transmitter transmits the multiple phase shifted outputs using beamforming from the multiple antenna elements. In such embodiments, using beamforming may include using a transmit beamforming vector, and the transmit beamforming vector does not change while beamforming.

[00110] In one embodiment, the transmitter transmits a number of reference signals in a frequency resource using substantially consecutive OFDM symbols. In certain embodiments, the transmitter transmits a number of reference signals in substantially adjacent time and frequency resources. In various embodiments, the apparatus includes a processor that determines a transmit beamforming vector using a discrete Fourier transform matrix, and the transmit beamforming vector is used for beamforming the multiple phase shifted outputs. In some embodiments, the apparatus includes a processor that determines a transmit beamforming vector using a Householder transform matrix, and the transmit beamforming vector is used for beamforming the plurality of phase shifted outputs.

[00111] In certain embodiments, the transmitter transmits information including one or more of information about the multiple reference signals to be transmitted, reference signals to be transmitted, beamforming vectors to be used, and time/frequency resources to be used. In one embodiment, the transmitter transmits the multiple reference signals in a downlink as a channel state information reference signal ("CSI-RS"). In some embodiments, the transmitter transmits the multiple reference signals in an uplink as a sounding reference signal ("SRS").

[00112] A method, in one embodiment, includes applying a phase shift vector to a digital signal that includes multiple reference signals to produce multiple phase shifted outputs. In certain embodiments, the method may include transmitting the multiple phase shifted outputs via multiple antenna elements. In such embodiments, each antenna element of the multiple antenna elements transmits a respective phase shifted output of the multiple phase shifted outputs.

[00113] In one embodiment, an apparatus for channel coefficient estimation includes an antenna port. The apparatus may also include a receiver that receives, at the antenna port, information having multiple reference signals. The apparatus may include a processor that

determines an estimated channel coefficient vector for the antenna port using the received information.

[00114] In certain embodiments, the processor determines the estimated channel coefficient vector using a zero forcing ("ZF") algorithm. In one embodiment, the processor determines the estimated channel coefficient vector using a minimum mean square error ("MMSE") algorithm. In various embodiments, the processor determines a maximal-ratio combining ("MRC") vector using the estimated channel coefficient vector. In such embodiments, the transmitter may transmit coefficients of the MRC vector. In certain embodiments, the transmitter may transmit a codeword corresponding to the MRC vector, and a predefined codebook comprises the codeword. In one embodiment, the processor quantizes and normalizes the multiple reference signals, and the transmitter transmits the quantized and normalized multiple reference signals.

[00115] Another method for channel coefficient estimation, in one embodiment, includes receiving, at an antenna port, information including multiple reference signals. In various embodiments, the method includes determining an estimated channel coefficient vector for the antenna port using the received information.

BRIEF DESCRIPTION OF THE DRAWINGS

[00116] A more particular description of the embodiments briefly described above will be rendered by reference to specific embodiments that are illustrated in the appended drawings. Understanding that these drawings depict only some embodiments and are not therefore to be considered to be limiting of scope, the embodiments will be described and explained with additional specificity and detail through the use of the accompanying drawings, in which:

[00117] Figure 1 is a schematic block diagram illustrating one embodiment of a wireless communication system for channel coefficient estimation;

[00118] Figure 2 is a schematic block diagram illustrating one embodiment of an apparatus that may be used for channel coefficient estimation;

[00119] Figure 3 is a schematic block diagram illustrating another embodiment of an apparatus that may be used for channel coefficient estimation;

[00120] Figure 4 is a schematic block diagram illustrating one embodiment of an antenna array;

[00121] Figure 5 is a schematic block diagram illustrating one embodiment of a system for producing multiple signals from a single digital signal;

[00122] Figure 6 is a schematic block diagram illustrating one embodiment of reference signal transmission;

[00123] Figure 7 is a schematic block diagram illustrating another embodiment of reference signal transmission;

[00124] Figure 8 is a schematic flow chart diagram illustrating one embodiment of a method for transmitting multiple reference signals; and

[00125] Figure 9 is a schematic flow chart diagram illustrating one embodiment of a method for channel coefficient estimation using information received by a receiver.

DETAILED DESCRIPTION

[00126] As will be appreciated by one skilled in the art, aspects of the embodiments may be embodied as a system, apparatus, method, or program product. Accordingly, embodiments may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a "circuit," "module" or "system." Furthermore, embodiments may take the form of a program product embodied in one or more computer readable storage devices storing machine readable code, computer readable code, and/or program code, referred hereafter as code. The storage devices may be tangible, non-transitory, and/or non-transmission. The storage devices may not embody signals. In a certain embodiment, the storage devices only employ signals for accessing code.

[00127] Certain of the functional units described in this specification may be labeled as modules, in order to more particularly emphasize their implementation independence. For example, a module may be implemented as a hardware circuit comprising custom very-large-scale integration ("VLSI") circuits or gate arrays, off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A module may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices or the like.

[00128] Modules may also be implemented in code and/or software for execution by various types of processors. An identified module of code may, for instance, include one or more physical or logical blocks of executable code which may, for instance, be organized as an object, procedure, or function. Nevertheless, the executables of an identified module need not be physically located together, but may include disparate instructions stored in different locations which, when joined logically together, include the module and achieve the stated purpose for the module.

[00129] Any combination of one or more computer readable medium may be utilized. The computer readable medium may be a computer readable storage medium. The computer readable storage medium may be a storage device storing the code. The storage device may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, holographic, micromechanical, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing.

[00130] More specific examples (a non-exhaustive list) of the storage device would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory ("RAM"), a read-only memory ("ROM"), an erasable programmable read-only memory ("EPROM" or Flash memory), a portable compact disc read-only memory ("CD-ROM"), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device.

[00131] Reference throughout this specification to "one embodiment," "an embodiment," or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment. Thus, appearances of the phrases "in one embodiment," "in an embodiment," and similar language throughout this specification may, but do not necessarily, all refer to the same embodiment, but mean "one or more but not all embodiments" unless expressly specified otherwise. The terms "including," "comprising," "having," and variations thereof mean "including but not limited to," unless expressly specified otherwise. An enumerated listing of items does not imply that any or all of the items are mutually exclusive, unless expressly specified otherwise. The terms "a," "an," and "the" also refer to "one or more" unless expressly specified otherwise.

[00132] Furthermore, the described features, structures, or characteristics of the embodiments may be combined in any suitable manner. In the following description, numerous specific details are provided, such as examples of programming, software modules, user selections, network transactions, database queries, database structures, hardware modules, hardware circuits, hardware chips, etc., to provide a thorough understanding of embodiments. One skilled in the relevant art will recognize, however, that embodiments may be practiced without one or more of the specific details, or with other methods, components, materials, and so forth. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of an embodiment.

[00133] Aspects of the embodiments are described below with reference to schematic flowchart diagrams and/or schematic block diagrams of methods, apparatuses, systems, and program products according to embodiments. It will be understood that each block of the schematic flowchart diagrams and/or schematic block diagrams, and combinations of blocks in the schematic flowchart diagrams and/or schematic block diagrams, can be implemented by code. These code may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the schematic flowchart diagrams and/or schematic block diagrams block or blocks.

[00134] The code may also be stored in a storage device that can direct a computer, other programmable data processing apparatus, or other devices to function in a particular manner, such that the instructions stored in the storage device produce an article of manufacture including instructions which implement the function/act specified in the schematic flowchart diagrams and/or schematic block diagrams block or blocks.

[00135] The code may also be loaded onto a computer, other programmable data processing apparatus, or other devices to cause a series of operational steps to be performed on the computer, other programmable apparatus or other devices to produce a computer implemented process such that the code which execute on the computer or other programmable apparatus provide processes for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

[00136] The schematic flowchart diagrams and/or schematic block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of apparatuses, systems, methods and program products according to various embodiments. In this regard, each block in the schematic flowchart diagrams and/or schematic block diagrams may represent a module, segment, or portion of code, which includes one or more executable instructions of the code for implementing the specified logical function(s).

[00137] It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the Figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. Other steps and methods may be conceived that are equivalent in function, logic, or effect to one or more blocks, or portions thereof, of the illustrated Figures.

[00138] Although various arrow types and line types may be employed in the flowchart and/or block diagrams, they are understood not to limit the scope of the corresponding embodiments. Indeed, some arrows or other connectors may be used to indicate only the logical flow of the depicted embodiment. For instance, an arrow may indicate a waiting or monitoring period of unspecified duration between enumerated steps of the depicted embodiment. It will also be noted that each block of the block diagrams and/or flowchart diagrams, and combinations of blocks in the block diagrams and/or flowchart diagrams, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and code.

[00139] The description of elements in each figure may refer to elements of proceeding figures. Like numbers refer to like elements in all figures, including alternate embodiments of like elements.

[00140] Figure 1 depicts an embodiment of a wireless communication system 100 for channel coefficient estimation. In certain embodiments, the wireless communication system 100 may operate using mmW communication. In one embodiment, the wireless communication system 100 includes remote units 102 and base units 104. Even though a specific number of remote units 102 and base units 104 are depicted in Figure 1, one of skill in the art will recognize that any number of remote units 102 and base units 104 may be included in the wireless communication system 100.

[00141] In one embodiment, the remote units 102 may include computing devices, such as desktop computers, laptop computers, personal digital assistants ("PDAs"), tablet computers, smart phones, smart televisions (e.g., televisions connected to the Internet), set-top boxes, game consoles, security systems (including security cameras), vehicle on-board computers, network devices (e.g., routers, switches, modems), or the like. In some embodiments, the remote units 102 include wearable devices, such as smart watches, fitness bands, optical head-mounted displays, or the like. Moreover, the remote units 102 may be referred to as subscriber units, mobiles, mobile stations, users, terminals, mobile terminals, fixed terminals, subscriber stations, UE, user terminals, a device, or by other terminology used in the art. The remote units 102 may communicate directly with one or more of the base units 104 via UL communication signals.

[00142] The base units 104 may be distributed over a geographic region. In certain embodiments, a base unit 104 may also be referred to as an access point, an access terminal, a base, a base station, a Node-B, an eNB, a Home Node-B, a relay node, a device, or by any other terminology used in the art. The base units 104 are generally part of a radio access network that

includes one or more controllers communicably coupled to one or more corresponding base units 104. The radio access network is generally communicably coupled to one or more core networks, which may be coupled to other networks, like the Internet and public switched telephone networks, among other networks. These and other elements of radio access and core networks are not illustrated but are well known generally by those having ordinary skill in the art.

[00143] In one implementation, the wireless communication system 100 is compliant with the LTE of the 3GPP protocol, wherein the base unit 104 transmits using an OFDM modulation scheme on the DL and the remote units 102 transmit on the UL using a SC-FDMA scheme. More generally, however, the wireless communication system 100 may implement some other open or proprietary communication protocol, for example, WiMAX, among other protocols. The present disclosure is not intended to be limited to the implementation of any particular wireless communication system architecture or protocol.

[00144] The base units 104 may serve a number of remote units 102 within a serving area, for example, a cell or a cell sector via a wireless communication link. The base units 104 transmit DL communication signals to serve the remote units 102 in the time, frequency, and/or spatial domain.

[00145] In one embodiment, an apparatus (e.g., UE, remote unit 102, eNB, base unit 104) may apply a phase shift vector to a digital signal that includes multiple reference signals to produce multiple phase shifted outputs. The apparatus may also transmit the multiple phase shifted outputs via multiple antenna elements. In certain embodiments, each antenna element of the multiple antenna elements transmits a respective phase shifted output of the multiple phase shifted outputs. The multiple phase shifted outputs may aid in channel coefficient estimation.

[00146] In another embodiment, an apparatus (e.g., eNB, base unit 104, UE, remote unit 102) may receive, at an antenna port, information including multiple reference signals. The apparatus may also determine an estimated channel coefficient vector for the antenna port using the received information.

[00147] Figure 2 depicts one embodiment of an apparatus 200 that may be used for channel coefficient estimation. The apparatus 200 includes one embodiment of the remote unit 102. Furthermore, the remote unit 102 may include a processor 202, a memory 204, an input device 206, a display 208, a transmitter 210, a receiver 212, an antenna array 214, and circuitry 216. In some embodiments, the input device 206 and the display 208 are combined into a single device, such as a touchscreen. In certain embodiments, the remote unit 102 may not include any input device 206 and/or display 208. In various embodiments, the remote unit 102 may include

one or more of the processor 202, the memory 204, the transmitter 210, the receiver 212, the antenna array 214, and the circuitry 216, and may not include the input device 206 and/or the display 208.

[00148] The processor 202, in one embodiment, may include any known controller capable of executing computer-readable instructions and/or capable of performing logical operations. For example, the processor 202 may be a microcontroller, a microprocessor, a central processing unit ("CPU"), a graphics processing unit ("GPU"), an auxiliary processing unit, a field programmable gate array ("FPGA"), or similar programmable controller. In some embodiments, the processor 202 executes instructions stored in the memory 204 to perform the methods and routines described herein. The processor 202 is communicatively coupled to the memory 204, the input device 206, the display 208, the transmitter 210, and the receiver 212. In certain embodiments, the processor 202 may determine a transmit beamforming vector. In some embodiments, the processor 202 may determine an estimated channel coefficient vector for an antenna port using received information.

[00149] The memory 204, in one embodiment, is a computer readable storage medium. In some embodiments, the memory 204 includes volatile computer storage media. For example, the memory 204 may include a RAM, including dynamic RAM ("DRAM"), synchronous dynamic RAM ("SDRAM"), and/or static RAM ("SRAM"). In some embodiments, the memory 204 includes non-volatile computer storage media. For example, the memory 204 may include a hard disk drive, a flash memory, or any other suitable non-volatile computer storage device. In some embodiments, the memory 204 includes both volatile and non-volatile computer storage media. In some embodiments, the memory 204 stores data relating to information to be provided to another device. In some embodiments, the memory 204 also stores program code and related data, such as an operating system or other controller algorithms operating on the remote unit 102.

[00150] The input device 206, in one embodiment, may include any known computer input device including a touch panel, a button, a keyboard, a stylus, a microphone, or the like. In some embodiments, the input device 206 may be integrated with the display 208, for example, as a touchscreen or similar touch-sensitive display. In some embodiments, the input device 206 includes a touchscreen such that text may be input using a virtual keyboard displayed on the touchscreen and/or by handwriting on the touchscreen. In some embodiments, the input device 206 includes two or more different devices, such as a keyboard and a touch panel.

[00151] The display 208, in one embodiment, may include any known electronically controllable display or display device. The display 208 may be designed to output

visual, audible, and/or haptic signals. In some embodiments, the display 208 includes an electronic display capable of outputting visual data to a user. For example, the display 208 may include, but is not limited to, an LCD display, an LED display, an OLED display, a projector, or similar display device capable of outputting images, text, or the like to a user. As another, non-limiting, example, the display 208 may include a wearable display such as a smart watch, smart glasses, a heads-up display, or the like. Further, the display 208 may be a component of a smart phone, a personal digital assistant, a television, a table computer, a notebook (laptop) computer, a personal computer, a vehicle dashboard, or the like.

[00152] In certain embodiments, the display 208 includes one or more speakers for producing sound. For example, the display 208 may produce an audible alert or notification (e.g., a beep or chime). In some embodiments, the display 208 includes one or more haptic devices for producing vibrations, motion, or other haptic feedback. In some embodiments, all or portions of the display 208 may be integrated with the input device 206. For example, the input device 206 and display 208 may form a touchscreen or similar touch-sensitive display. In other embodiments, the display 208 may be located near the input device 206.

[00153] The transmitter 210 is used to provide UL communication signals to the base unit 104 and the receiver 212 is used to receive DL communication signals from the base unit 104. In one embodiment, the transmitter 210 may transmit multiple phase shifted outputs via multiple antenna elements. In such an embodiment, each antenna element of the multiple antenna elements may transmit a respective phase shifted output of the multiple phase shifted outputs. In certain embodiments, the receiver 214 may receive, at the antenna port, information comprising a plurality of reference signals. Although only one transmitter 210 and one receiver 212 are illustrated, the remote unit 102 may have any suitable number of transmitters 210 and receivers 212. The transmitter 210 and the receiver 212 may be any suitable type of transmitters and receivers. In one embodiment, the transmitter 210 and the receiver 212 may be part of a transceiver.

[00154] The antenna array 214 may be used to transmit and/or receive transmissions. In certain embodiments, the antenna array 214 is part of the transmitter 210, while in other embodiments, the antenna array 214 is part of the receiver 212. In some embodiments, the antenna array 214 may be part of a transceiver. The antenna array 214 may include any suitable number of antenna elements and any suitable number of antenna ports. For example, in some embodiments, the antenna array 214 may include less than or greater than 8, 16, 32, 64, or 128 antenna elements. One embodiment of an antenna array 214 is described in Figure 4.

[00155] The circuitry 216 may include any suitable circuitry for the remote unit 102. In certain embodiments, the circuitry 216 includes hardware and/or software. In one embodiment, the circuitry 216 includes a phase shifter that applies a phase shift vector to a version of information received by each antenna element of the antenna array 214 to produce multiple phase shifted outputs. In another embodiment, the circuitry 216 includes a phase shifter that applies a phase shift vector to a digital signal to be transmitted by multiple antenna elements of the antenna array 214 as multiple phase shifted outputs. In certain embodiments, the circuitry 216 includes a dividing device that divides a digital signal into the multiple phase shifted outputs. One embodiment of circuitry 216 is described in Figure 5.

[00156] Figure 3 depicts another embodiment of an apparatus 300 that may be used for channel coefficient estimation. The apparatus 300 includes one embodiment of the base unit 104. Furthermore, the base unit 104 may include a processor 302, a memory 304, an input device 306, a display 308, a transmitter 310, a receiver 312, an antenna array 314, and circuitry 316. As may be appreciated, the processor 302, the memory 304, the input device 306, the display 308, the transmitter 310, the receiver 312, the antenna array 314, and the circuitry 316 may be substantially similar to the processor 202, the memory 204, the input device 206, the display 208, the transmitter 210, the receiver 212, the antenna array 214, and the circuitry 216 of the remote unit 102, respectively. For example, the transmitter 310 is used to provide DL communication signals to the remote unit 102, and the receiver 312 is used to receive UL communication signals from the remote unit 102.

[00157] Figure 4 is a schematic block diagram illustrating one embodiment of an antenna array 400, such as the antenna array 214 and/or the antenna array 314. The antenna array 400 includes 16 antenna columns 402, with each antenna column 402 including 4 antenna elements 404. As may be appreciated, the antenna array 400 may have any suitable number of antenna columns 402. Furthermore, each antenna column 402 may include any suitable number of antenna elements 404. In certain embodiments, the antenna array 400 may be considered a beamforming antenna array.

[00158] Figure 5 is a schematic block diagram illustrating one embodiment of a system 500 for producing multiple signals from a single digital signal. In certain embodiments, the system 500 may be part of the circuitry 216 and/or the circuitry 316. As illustrated, the system 500 may correspond to one antenna column 402 used for transmission. Accordingly, each antennal column 402 in an antenna array 400 may correspond to one system 500.

[00159] During operation, a digital signal z 502 may be fed into an analog-to-digital converter ("ADC") 504. The ADC 504 converts the digital signal z 502 into an analog

signal that is fed into an RF chain 506. The analog signal is then divided to be fed into a respective first phase shifter 510, second phase shifter 512, third phase shifter 514, and fourth phase shifter 516. The phase shifters 510, 512, 514, and 516 apply a phase shift vector to their respective received signals. In one embodiment, the first phase shifter 510 applies a first phase shift vector, the second phase shifter 512 applies a second phase shift vector, the third phase shifter 514 applies a third phase shift vector, and the fourth phase shifter 516 applies a fourth phase shift vector. Accordingly, the phase shifters 510, 512, 514, and 516 shift the signals.

[00160] The outputs from the phase shifters 510, 512, 514, and 516 are provided to amplifiers 518, 520, 522, and 524. Specifically, the output from the first phase shifter 510 is provided to a first amplifier 518 (e.g., low noise amplifier "LNA"), the output from the second phase shifter 512 is provided to a second amplifier 520, the output from the third phase shifter 514 is provided to a third amplifier 522, and the output from the fourth phase shifter 516 is provided to a fourth amplifier 524. The amplifiers 518, 520, 522, and 524 are used to amplify the received signals prior to transmission. Moreover, the amplifiers 518, 520, 522, and 524 may be any suitable amplifier, such as LNAs.

[00161] Furthermore, a first antenna element 526 may transmit a first signal (e.g., y_0) from the first amplifier 518, a second antenna element 528 may transmit a second signal (e.g., y_1) from the second amplifier 520, a third antenna element 530 may transmit a third signal (e.g., y_2) from the third amplifier 522, and a fourth antenna element 532 may transmit a fourth signal (e.g., y_3) from the fourth amplifier 524. As may be appreciated, in antenna columns 402 with N antenna elements 404 additional signals may be transmitted up to y_{N-1}.

[00162] In another example, a channel coefficient vector G from a transmission antenna array to a receiver antenna port may be represented by the following equation:

$$G = [g_0, g_1, \dots, g_{N-1}]^T$$

[00163] where g represents a channel coefficient corresponding to a single antenna element; T represents time; and N represents the number of antenna elements.

[00164] A received signal z on the receiver side for such a channel coefficient vector G may be represented by the following equation:

$$z = (\sum_{l=0}^{N-1} e^{i\varphi_l} g_l)x + n$$

[00165] where $e^{i\varphi_l}$ is the phase shift corresponding to an antenna element l; g_l represents a channel coefficient corresponding to an antenna element l; N represents the number of antenna elements; x represents the transmitted signal; and n represents additive Gaussian

white noise. As may be appreciated, like representations may be used in any of the embodiments described herein.

[00166] In one embodiment, an analogue beamforming scheme is achieved using an MRC receiver. For the MRC receiver, a beamforming vector e^{Φ^0} (e.g., phase shift vector Φ^0) may be represented by the following equations:

$$e^{i\phi_l^o} = \frac{g_l^*}{|g_l^*|}, \qquad \phi_l^o = i * ln\left(\frac{g_l}{|g_l|}\right)$$

[00167] where g_l represents a channel coefficient corresponding to an antenna element l.

[00168] In this embodiment, the receiver has a channel coefficient for every antenna element l.

[00169] In one embodiment, a transmitter with a beamformed antenna array may estimate the entire channel coefficient vector $G = [g_0, g_1, \dots, g_{N-1}]^T$ from the digital output z (e.g., multiple values of z corresponding to multiple beamforming vectors), and use such information to construct an MRC receiver. In one embodiment, the transmitter antenna port transmits a normalized RS signal $x_{RS}, |x_{RS}| = 1$ in $K \geq N$ consecutive symbols in a same frequency resource. As the receiver receives the K RS, it shifts through a set of K different phase shift vectors $\Phi = [\Phi^0, \Phi^1, \dots, \Phi^{K-1}]$. The digital output z_k associated with Φ^k is given by the following equation:

$$z_k = \left(\sum_{l=0}^{N-1} e^{i\varphi^k{}_l} g_l\right) x_{RS} + n_i$$

[00170] In vector form the above equation may be represented by:

$$Z = \begin{bmatrix} e^{i\varphi^0{}_0} & \cdots & e^{i\varphi^0{}_{N-1}} \\ \vdots & \ddots & \vdots \\ e^{i\varphi^{K-1}{}_0} & \cdots & e^{i\varphi^{K-1}{}_{N-1}} \end{bmatrix} G x_{RS} + \begin{bmatrix} n_0 \\ \vdots \\ n_{K-1} \end{bmatrix} = W G x_{RS} + N$$

[00171] Assuming that a receiver knows the phase shift vectors Φ , the receiver may estimate the channel coefficients G from Z with different algorithms. For example, a ZF estimator algorithm may be represented by:

$$\hat{G}_{ZF} = (W^*W)^{-1} W^* Z x_{RS}{}^*.$$

[00172] The channel coefficients G may also be estimated with an MMSE estimator algorithm that may be represented by:

$$\hat{G}_{MMSE} = \left(W^*W + \frac{1}{\rho} I_N\right)^{-1} W^* Z x_{RS}{}^*,$$

[00173] where ρ is the receiver SNR before combining.

[00174] In certain embodiments, it may be assumed that the channel coefficients G do not change during the K transmissions. In such embodiments, this may be true if the transmission time $KT_s \ll T_{coh}$, where T_s represents the transmission time of a symbol and T_{coh} represents the coherent time of the channel. If the transmitter applies beamforming (either digital or analog) to multiple Tx antenna elements to form an antenna port, the beamforming vector does not change during the transmission time KT_s.

[00175] The minimal number of the transmitted RS is N. So is the number of phase shift vectors. As an example, the phase shifter vectors, or equivalently the W matrix, can be generated from FFT (or equivalently IFFT) matrix. In one embodiment,

$$W_{FFT_N} = FFT_N = [\left\{e^{-\frac{i2\pi kl}{N}}\right\}, 0 \leq k, l \leq N-1]$$

$$W_{FFT_N}{}^* = IFFT_N = [\left\{e^{\frac{i2\pi kl}{N}}\right\}, 0 \leq k, l \leq N-1]$$

[00176] In certain embodiments, the ZF estimator and MMSE estimator may be:

$$\hat{G}_{ZF} = IFFT_N Z x_{RS}{}^*$$

$$\hat{G}_{MMSE} = (1 + \frac{1}{\rho})^{-1} IFFT_N Z x_{RS}{}^*$$

[00177] In certain embodiments, such as for the case of $K > N$, an oversampled FFT matrix may be used. For example:

$$W_{FFT_{KN}} = \{w_{k,n}\} = [\left\{e^{-\frac{i2\pi kn}{K}}\right\}, 0 \leq k \leq K-1, 0 \leq n \leq N-1]$$

[00178] where:

$$W^k = [1, e^{-j\frac{2\pi k}{K}}, e^{-j\frac{2\pi 2k}{K}}, \ldots, e^{-j\frac{2\pi(N-1)k}{K}}]$$

$$W_{FFT_{KN}} = \begin{bmatrix} W^0 \\ \vdots \\ W^{K-1} \end{bmatrix}$$

[00179] Therefore,

$$F = W_{FFT_{KN}}{}^* W_{FFT_{KN}} = \sum_{k=0}^{K-1} W^{k*} W^k$$

[00180] where:

$$f_{l,m} = \sum_{k=0}^{K-1} e^{j\frac{2\pi(l-m)k}{K}}$$

[00181] In such embodiments, the ZF estimator and MMSE estimator may be:

$$\hat{G}_{ZF} = F^{-1} W_{FFT_{KN}}{}^{*} Z x_{RS}{}^{*}$$

$$\hat{G}_{MMSE} = (F + \frac{1}{\rho} I_N)^{-1} W_{FFT_{KN}}{}^{*} Z x_{RS}{}^{*}$$

[00182] Besides FFT-based phase shift vectors, other matrices with rank N may also be used. To ease the computation, W may be a unitary matrix. In one embodiment, a Householder transformation matrix of size N may be used, where:

$$W_H = I - 2vv^{*}$$

[00183] and v is a column unit vector.

$$W_H = W_H{}^{*} = W_H{}^{-1}$$

[00184] In such an embodiment, the ZF estimator and MMSE estimator may be:

$$\hat{G}_{ZF} = W_H Z x_{RS}{}^{*}$$

$$\hat{G}_{MMSE} = (1 + \frac{1}{\rho})^{-1} W_H Z x_{RS}{}^{*}$$

[00185] From the estimated channel coefficient $\hat{G}_{ZF}$ or $\hat{G}_{MMSE}$, the receiver may derive the phase shift vector for the MRC receiver.

[00186] In certain embodiments, a transmitter (e.g., transmitter 210, transmitter 310) transmits the RSs K times for a receiver (e.g., receiver 212, receiver 312) to estimate the entire set of channel coefficients G for receiving beamforming from $K \leq N$ antenna elements. The RSs may be transmitted in the same frequency resources in K consecutive symbols in an OFDM-like system. In certain embodiments, the K consecutive symbols may be physically adjacent, while in other embodiments, the K consecutive symbols may be close (e.g., substantially consecutive, substantially adjacent), but not necessarily physically adjacent. For example, in some embodiments, 1, 2, or 3 OFDM symbols may separate the K consecutive symbols. The adjacent RSs may be transmitted with different (but known to the receiver) symbols or sequences. The densities of the RS in time and frequency dimensions may be determined by the coherent time and frequency of a channel.

[00187] Figure 6 is a schematic block diagram illustrating one embodiment of reference signal transmission 600. In this embodiment, an array of possible resources 602 for

transmitting RSs is illustrated. As may be appreciated, the x-axis may correspond to time and the y-axis may correspond to frequency. Pairs of 2 physically adjacent RSs 604 (e.g., $K = 2$) are used in this embodiment to facilitate a receiver estimating the entire set of channel coefficients G for receiving beamforming from $K \leq N$ antenna elements. In certain embodiments, the pairs of 2 RSs 604 may be close (e.g., substantially consecutive, substantially adjacent), but not necessarily physically adjacent. For example, in some embodiments, 1, 2, or 3 OFDM symbols may separate each pair of RSs 604.

[00188] Figure 7 is a schematic block diagram illustrating another embodiment of reference signal transmission 700. In this embodiment, an array of possible resources 702 for transmitting RSs is illustrated. As may be appreciated, the x-axis may correspond to time and the y-axis may correspond to frequency. Sets of 4 physically adjacent RSs 704 (e.g., $K = 4$) are used in this embodiment to facilitate a receiver estimating the entire set of channel coefficients G for receiving beamforming from $K \leq N$ antenna elements. In certain embodiments, the pairs of 4 RSs 704 may be close (e.g., substantially consecutive, substantially adjacent), but not necessarily physically adjacent. For example, in some embodiments, 1, 2, or 3 OFDM symbols may separate each RS 704 in the pair of 4 RSs 704.

[00189] In certain embodiments, an OCC of length K may be used when transmitting the RS sequences. For example, for $K = 2$, the following pairs of OCC may be used: {[1, 1], [1, -1]}. As another example, for $K = 4$, the following sets of OCC may be used: {[1, 1, 1, 1], [1, -1, 1, -1], [1, 1, -1, -1], [1, -1, -1, 1]}. Thus, different RSs may be multiplexed if necessary.

[00190] Implicit or explicit control signaling, including information of the resources used for the RS, the RS sequences (e.g., including OCC), may be used to coordinate the transmission and reception of the reference signals. The process for the RS transmission and feedback may be considered as a training process for a transmitter-receiver pair. This may be used in either CSI-RS in the downlink or SRS in the uplink.

[00191] Figure 8 is a schematic flow chart diagram illustrating one embodiment of a method 800 for transmitting multiple reference signals. In some embodiments, the method 800 is performed by an apparatus, such as a remote unit 102 or the base unit 104. In certain embodiments, the method 800 may be performed by a processor executing program code, for example, a microcontroller, a microprocessor, a CPU, a GPU, an auxiliary processing unit, a FPGA, or the like.

[00192] The method 800 may include determining 802 multiple reference signals to be transmitted. In one embodiment, a number of reference signals of the multiple reference

signals may be at least equal to a number of antenna elements of the multiple antenna elements that transmit the multiple reference signals. The method 800 may include determining 804 a transmit beamforming vector. In one embodiment, determining 804 the transmit beamforming vector includes determining the transmit beamforming vector using a discrete Fourier transform matrix. In such an embodiment, the transmit beamforming vector is used for beamforming the multiple phase shifted outputs. In another embodiment, determining 804 the transmit beamforming vector includes determining the transmit beamforming vector using a Householder transform matrix. In such an embodiment, the transmit beamforming vector is used for beamforming the multiple phase shifted outputs.

[00193] The method 800 may also include transmitting 806 information corresponding to the multiple reference signals. In one embodiment, transmitting 806 the information includes transmitting one or more of: information about the multiple reference signals to be transmitted (e.g., a number of consecutive reference signals to be transmitted, etc.); reference signals to be transmitted (e.g., the actual reference signals that will be transmitted); beamforming vectors to be used; and time/frequency resources to be used. The method 800 may include applying 808 a phase shift vector to a digital signal that includes multiple reference signals to produce multiple phase shifted outputs.

[00194] The method 800 may also include transmitting 810 the multiple phase shifted outputs via multiple antenna elements, then the method 800 may end. In certain embodiments, transmitting 810 the multiple phase shifted outputs includes transmitting the multiple shifted outputs using beamforming from the multiple antenna elements. In such embodiments, using beamforming may include using a transmit beamforming vector, and the transmit beamforming vector does not change while beamforming. In some embodiments, transmitting 810 the multiple shifted outputs includes transmitting a number of reference signals in a frequency resource using substantially consecutive OFDM symbols.

[00195] In various embodiments, transmitting 810 the multiple phase shifted outputs includes transmitting a number of reference signals in substantially adjacent time and frequency resources. In one embodiment, each antenna element of the multiple antenna elements transmits a respective phase shifted output of the multiple phase shifted outputs. In another embodiment, the multiple phase shifted outputs are transmitted via a millimeter wave frequency in a time-frequency domain using OFDM. In certain embodiments, transmitting 810 the multiple phase shifted outputs includes transmitting the multiple reference signals in a downlink as a CSI-RS. In various embodiments, transmitting 810 the multiple phase shifted outputs includes transmitting the multiple reference signals in an uplink as a SRS.

[00196] Figure 9 is a schematic flow chart diagram illustrating one embodiment of a method 900 for channel coefficient estimation using information received by a receiver. In some embodiments, the method 900 is performed by an apparatus, such as a base unit 104 or a remote unit 102. In certain embodiments, the method 900 may be performed by a processor executing program code, for example, a microcontroller, a microprocessor, a CPU, a GPU, an auxiliary processing unit, a FPGA, or the like.

[00197] The method 900 may include receiving 902, at an antenna port, information including multiple reference signals. The method 900 may also include determining 904 an estimated channel coefficient vector for the antenna port using the received information. In certain embodiments, determining 904 the estimated channel coefficient vector includes using a ZF algorithm. In some embodiments, determining 904 the estimated channel coefficient vector includes using a MMSE algorithm. The method 900 may include determining 906 an MRC vector using the estimated channel coefficient vector. The method 900 may also include transmitting 908 coefficients of the MRC vector and/or transmitting a codeword corresponding to the MRC vector. In such an embodiment, a predefined codebook may include the codeword. The method 900 may include quantizing 910 and normalizing the multiple reference signals and transmitting the quantized and normalized multiple reference signals, and the method 900 may end.

[00198] Embodiments may be practiced in other specific forms. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

CLAIMS

1. An apparatus comprising:
an antenna array comprising a plurality of antenna elements;
a phase shifter that applies a phase shift vector to a digital signal that includes a plurality of reference signals to produce a plurality of phase shifted outputs; and
a transmitter that transmits the plurality of phase shifted outputs via the plurality of antenna elements, wherein each antenna element of the plurality of antenna elements transmits a respective phase shifted output of the plurality of phase shifted outputs.

2. The apparatus of claim 1, wherein a number of reference signals of the plurality of reference signals is at least equal to a number of antenna elements of the plurality of antenna elements that transmit the plurality of reference signals.

3. The apparatus of claim 1, wherein the transmitter transmits the plurality of phase shifted outputs via a millimeter wave frequency in a time-frequency domain using orthogonal frequency-division multiplexing ("OFDM").

4. The apparatus of claim 1, wherein the transmitter transmits the plurality of phase shifted outputs using beamforming from the plurality of antenna elements.

5. The apparatus of claim 4, wherein using beamforming comprises using a transmit beamforming vector, and the transmit beamforming vector does not change while beamforming.

6. The apparatus of claim 1, wherein the transmitter transmits a number of reference signals in a frequency resource using substantially consecutive OFDM symbols.

7. The apparatus of claim 1, wherein the transmitter transmits a number of reference signals in substantially adjacent time and frequency resources.

8. The apparatus of claim 1, further comprising a processor that determines a transmit beamforming vector using a discrete Fourier transform matrix, and the transmit beamforming vector is used for beamforming the plurality of phase shifted outputs.

9. The apparatus of claim 1, further comprising a processor that determines a transmit beamforming vector using a Householder transform matrix, and the transmit beamforming vector is used for beamforming the plurality of phase shifted outputs.

10. The apparatus of claim 1, wherein the transmitter transmits information comprising one or more of:
information about the plurality of reference signals to be transmitted;
reference signals to be transmitted;
beamforming vectors to be used; and
time/frequency resources to be used.

11. The apparatus of claim 1, wherein the transmitter transmits the plurality of reference signals in a downlink as a channel state information reference signal ("CSI-RS").

12. The apparatus of claim 1, wherein the transmitter transmits the plurality of reference signals in an uplink as a sounding reference signal ("SRS").

13. A method comprising:
applying a phase shift vector to a digital signal that includes a plurality of reference signals to produce a plurality of phase shifted outputs; and
transmitting the plurality of phase shifted outputs via a plurality of antenna elements, wherein each antenna element of the plurality of antenna elements transmits a respective phase shifted output of the plurality of phase shifted outputs.

14. The method of claim 13, wherein a number of reference signals of the plurality of reference signals is at least equal to a number of antenna elements of the plurality of antenna elements that transmit the plurality of reference signals.

15. The method of claim 13, wherein the plurality of phase shifted outputs are transmitted via a millimeter wave frequency in a time-frequency domain using orthogonal frequency-division multiplexing ("OFDM").

16. The method of claim 13, wherein transmitting the plurality of phase shifted outputs comprises transmitting the plurality of phase shifted outputs using beamforming from the plurality of antenna elements.

17. The method of claim 16, wherein using beamforming comprises using a transmit beamforming vector, and the transmit beamforming vector does not change while beamforming.

18. The method of claim 13, wherein transmitting the plurality of phase shifted outputs comprises transmitting a number of reference signals in a frequency resource using substantially consecutive OFDM symbols.

19. The method of claim 13, wherein transmitting the plurality of phase shifted outputs comprises transmitting a number of reference signals in substantially adjacent time and frequency resources.

20. The method of claim 13, comprising determining a transmit beamforming vector using a discrete Fourier transform matrix, wherein the transmit beamforming vector is used for beamforming the plurality of phase shifted outputs.

21. The method of claim 13, comprising determining a transmit beamforming vector using a Householder transform matrix, wherein the transmit beamforming vector is used for beamforming the plurality of phase shifted outputs.

22. The method of claim 13, comprising transmitting information comprising one or more of:
information about the plurality of reference signals to be transmitted;
reference signals to be transmitted;
beamforming vectors to be used; and
time/frequency resources to be used.

23. The method of claim 13, wherein transmitting the plurality of phase shifted outputs comprises transmitting the plurality of reference signals in a downlink as a channel state information reference signal ("CSI-RS").

24. The method of claim 13, wherein transmitting the plurality of phase shifted outputs comprises transmitting the plurality of reference signals in an uplink as a sounding reference signal ("SRS").

25. An apparatus comprising:
an antenna port;
a receiver that receives, at the antenna port, information comprising a plurality of reference signals; and
a processor that determines an estimated channel coefficient vector for the antenna port using the received information.

26. The apparatus of claim 25, wherein the processor determines the estimated channel coefficient vector comprises using a zero forcing ("ZF") algorithm.

27. The apparatus of claim 25, wherein the processor determines the estimated channel coefficient vector comprises using a minimum mean square error ("MMSE") algorithm.

28. The apparatus of claim 25, wherein the processor determines a maximal-ratio combining ("MRC") vector using the estimated channel coefficient vector.

29. The apparatus of claim 28, wherein the transmitter transmits coefficients of the MRC vector.

30. The apparatus of claim 28, wherein the transmitter transmits a codeword corresponding to the MRC vector, and a predefined codebook comprises the codeword.

31. The apparatus of claim 25, wherein the processor quantizes and normalizes the plurality of reference signals, and the transmitter transmits the quantized and normalized plurality of reference signals.

32. A method comprising:
receiving, at an antenna port, information comprising a plurality of reference signals; and
determining an estimated channel coefficient vector for the antenna port using the received information.

33. The method of claim 32, wherein determining the estimated channel coefficient vector comprises using a zero forcing ("ZF") algorithm.

34. The method of claim 32, wherein determining the estimated channel coefficient vector comprises using a minimum mean square error ("MMSE") algorithm.

35. The method of claim 32, comprising determining a maximal-ratio combining ("MRC") vector using the estimated channel coefficient vector.

36. The method of claim 35, comprising transmitting coefficients of the MRC vector.

37. The method of claim 35, comprising transmitting a codeword corresponding to the MRC vector, wherein a predefined codebook comprises the codeword.

38. The method of claim 32, comprising quantizing and normalizing the plurality of reference signals and transmitting the quantized and normalized plurality of reference signals.

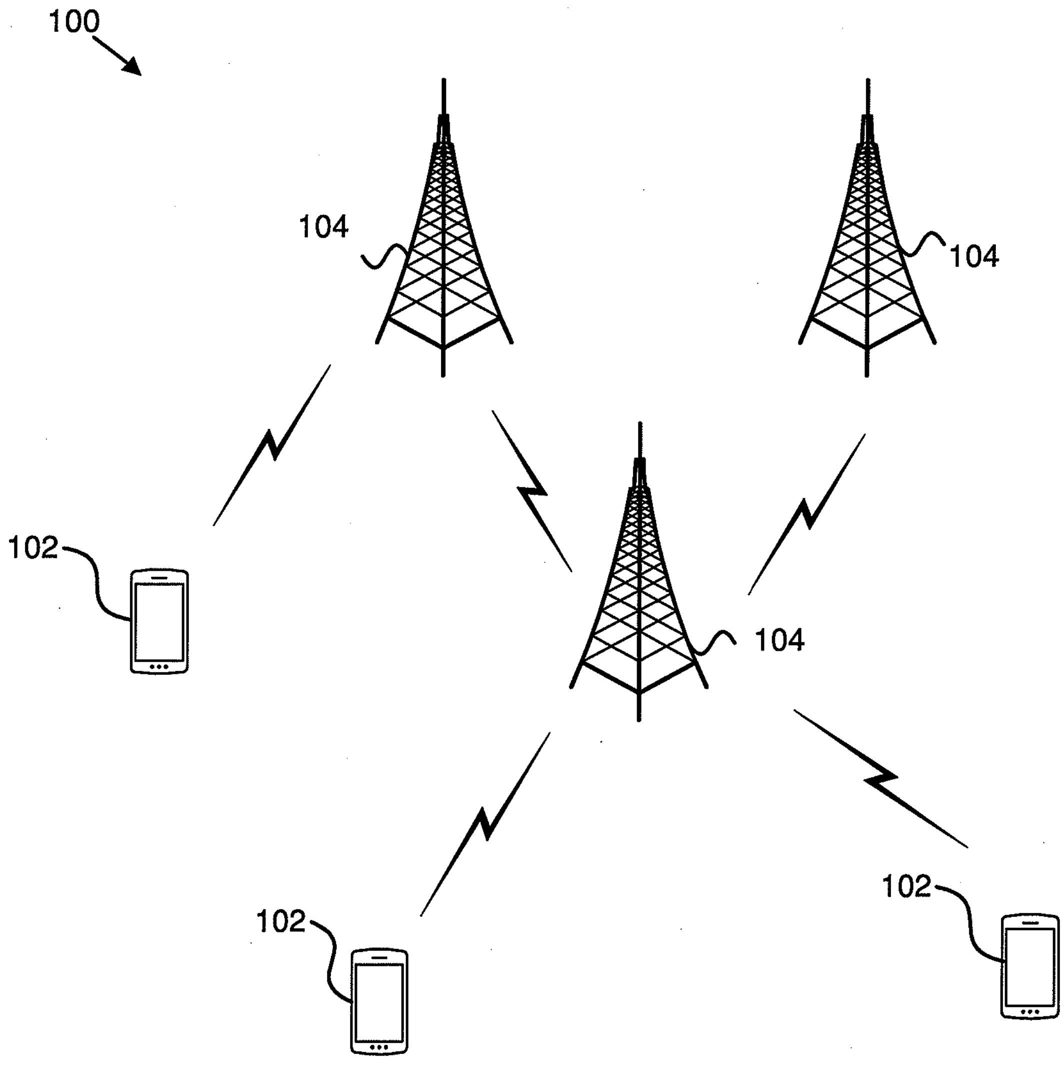

FIG. 1

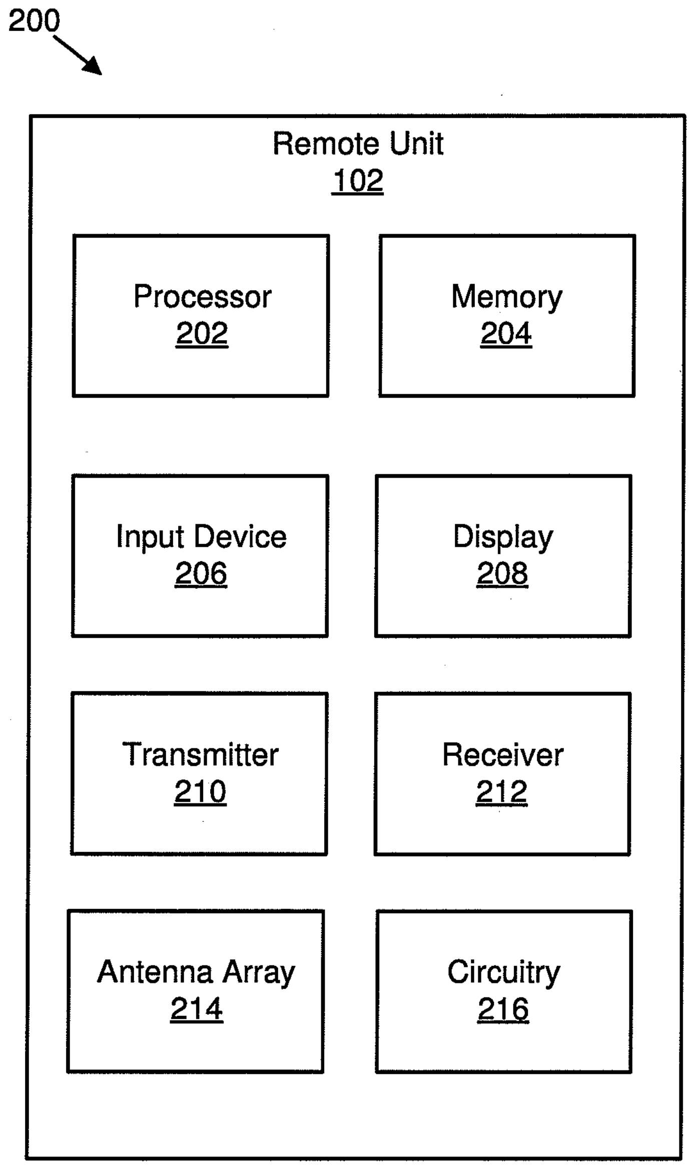
200
Remote Unit
102
Processor
202
Memory
204
Input Device
206
Display
208
Transmitter
210
Receiver
212
Antenna Array
214
Circuitry
216

FIG. 2

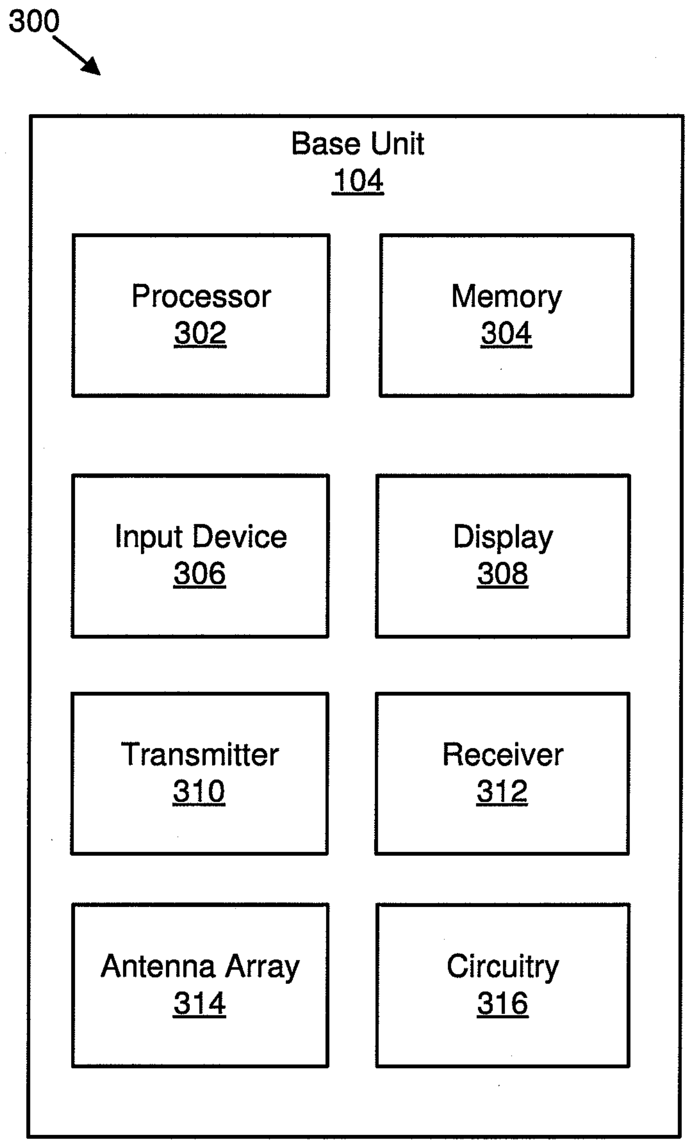
300
Base Unit
104
Processor
302
Memory
304
Input Device
306
Display
308
Transmitter
310
Receiver
312
Antenna Array
314
Circuitry
316

FIG. 3

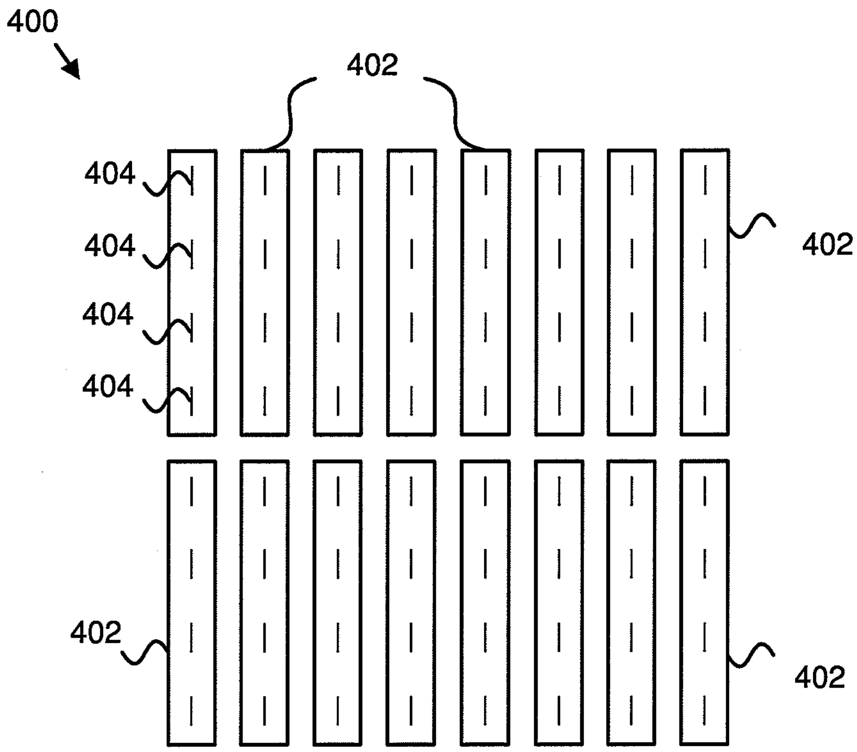
400
402
404
404
404
404
402
402
402

FIG. 4

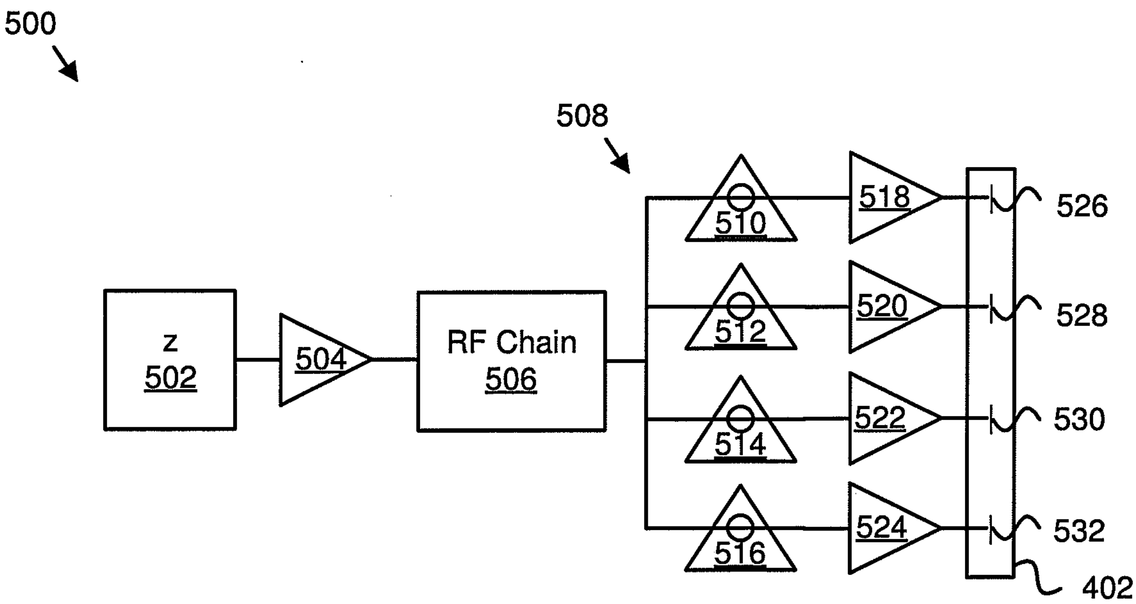
500
508
z
502
504
RF Chain
506
510
512
514
516
518
520
522
524
526
528
530
532
402

FIG. 5

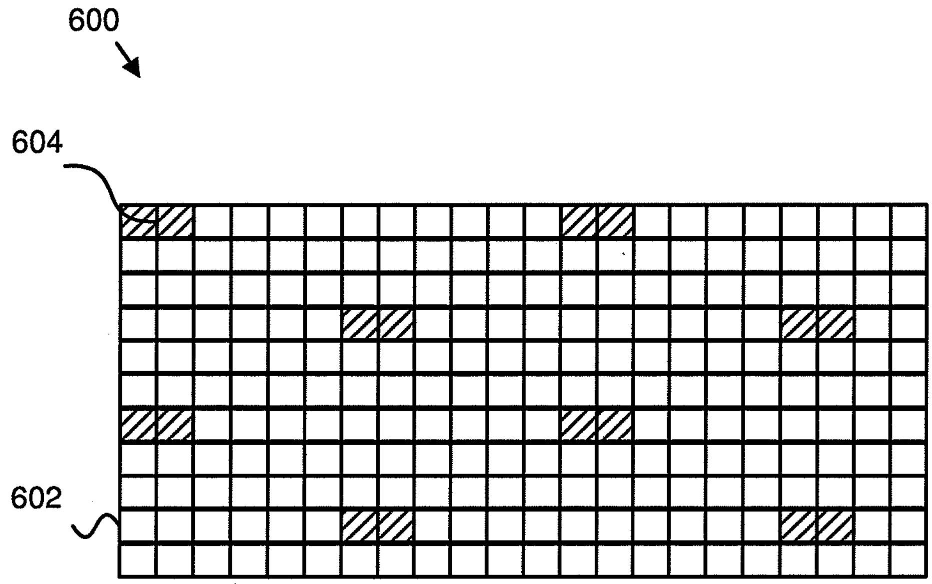

FIG. 6

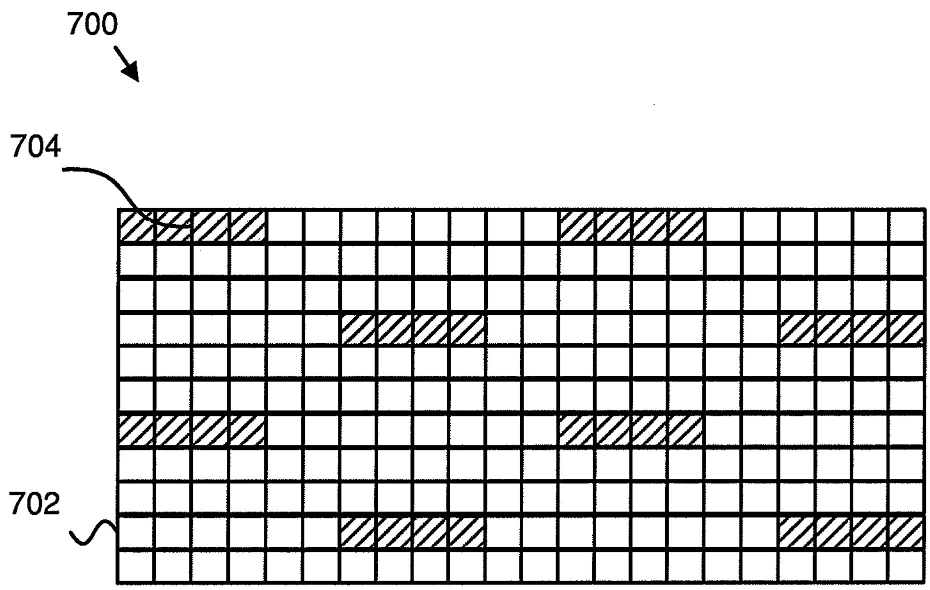

FIG. 7

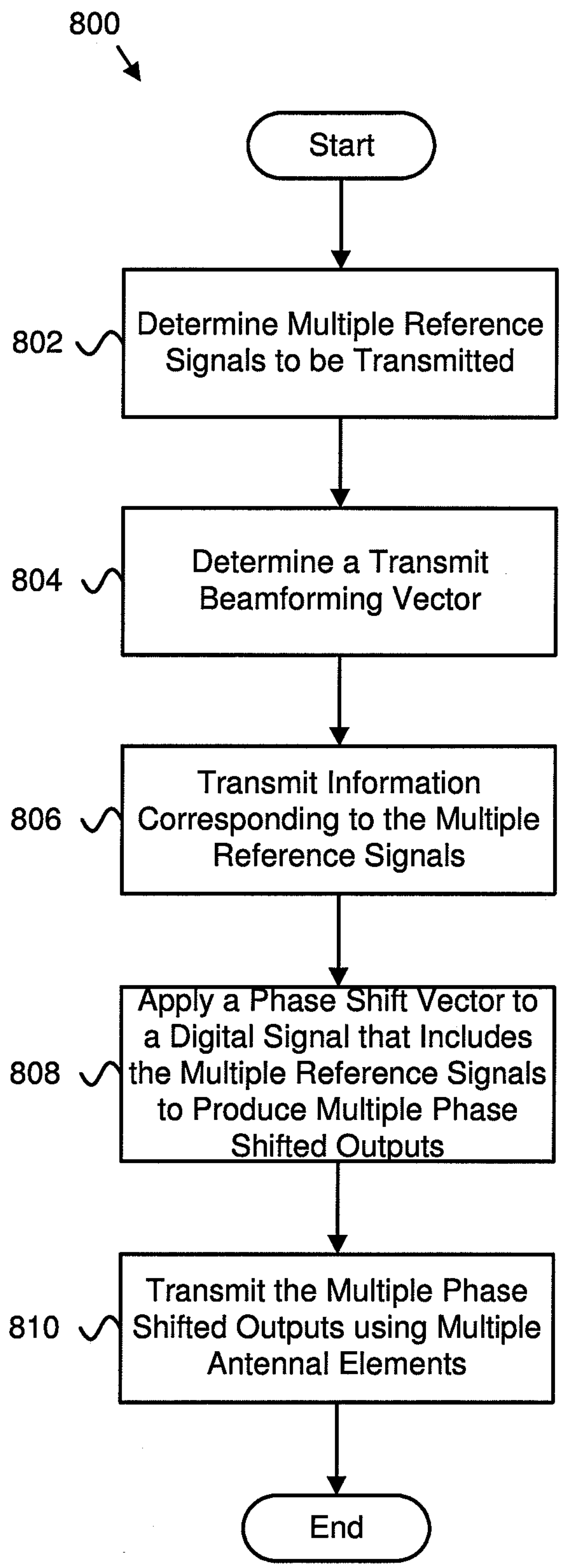
800
Start
802
Determine Multiple Reference Signals to be Transmitted
804
Determine a Transmit Beamforming Vector
806
Transmit Information Corresponding to the Multiple Reference Signals
808
Apply a Phase Shift Vector to a Digital Signal that Includes the Multiple Reference Signals to Produce Multiple Phase Shifted Outputs
810
Transmit the Multiple Phase Shifted Outputs using Multiple Antennal Elements
End

FIG. 8

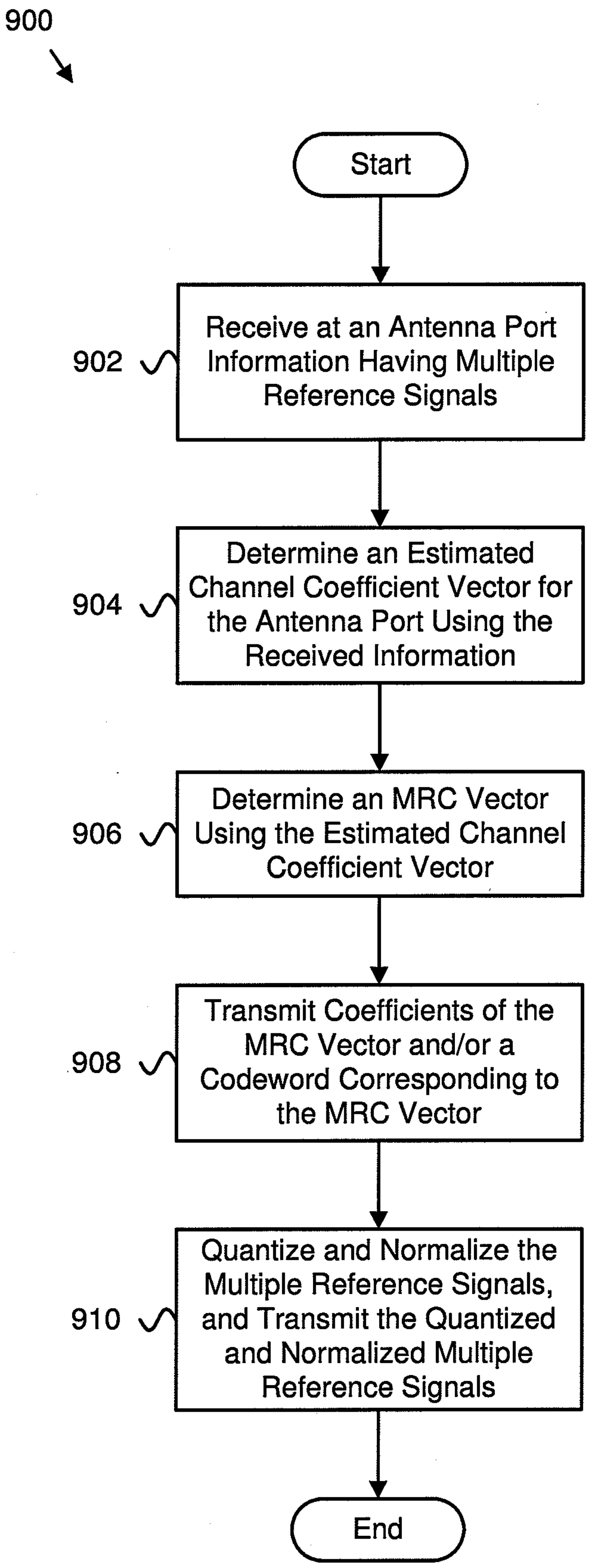
900
Start
902
Receive at an Antenna Port Information Having Multiple Reference Signals
904
Determine an Estimated Channel Coefficient Vector for the Antenna Port Using the Received Information
906
Determine an MRC Vector Using the Estimated Channel Coefficient Vector
908
Transmit Coefficients of the MRC Vector and/or a Codeword Corresponding to the MRC Vector
910
Quantize and Normalize the Multiple Reference Signals, and Transmit the Quantized and Normalized Multiple Reference Signals
End

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2016/086273

A. CLASSIFICATION OF SUBJECT MATTER

H04W 24/10(2009.01)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, H04L

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

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

cnabs;cntxt;cnki;ven;ustxt:phase shift+, antenna, ofdm, mmWave, millimeter, reference signal, ZF, MMSE, CSI, MRC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014044044 A1 (SAMSUNG ELECTRONICS CO.， LTD.) 13 February 2014 (2014-02-13) description， paragraphs [0044]-[0052]， [0059]-[0075] and figures 6 to 10	1-38
X	CN 101064544 A (SONY CORP.) 31 October 2007 (2007-10-31) description， page 3， line 8 to page 6， line 26	1-38
A	WO 2010011056 A2 (LG ELECTRONICS INC.) 28 January 2010 (2010-01-28) the whole document	1-38

☐ 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	Date of mailing of the international search report
07 March 2017	**29 March 2017**

Name and mailing address of the ISA/CN	Authorized officer
STATE INTELLECTUAL PROPERTY OFFICE OF THE P.R.CHINA **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088** **China**	**WANG,Rui**
Facsimile No. **(86-10)62019451**	Telephone No. **(86-10)62089564**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2016/086273

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2014044044	A1	13 February 2014	JP	2015532039	A	05 November 2015
				EP	2883381	A1	17 June 2015
				WO	2014027824	A1	20 February 2014
				EP	2883381	A4	06 April 2016
				CN	104541540	A	22 April 2015
				US	9439096	B2	06 September 2016
				KR	20150043310	A	22 April 2015
				IN	201500306	P2	18 December 2015
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