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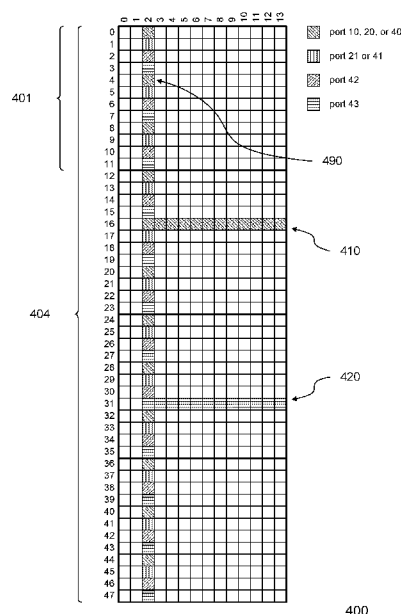


Fig. 4

(57) Abstract: Described is an apparatus of an Evolved Node-B (eNB) operable to communicate with a User Equipment (UE) on a wireless network. The apparatus may comprise a first circuitry and a second circuitry. The first circuitry may be operable to establish a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or Downlink (DL) transmission. The second circuitry may be operable to allocate one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.

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PHASE COMPENSATION REFERENCE SIGNAL FOR 5G SYSTEMS

CLAIM OF PRIORITY

[0001] The present application claims priority under 35 U.S.C. § 119(e) to United States Provisional Patent Application Serial Number 62/333,698 filed May 9, 2016 and entitled “Phase Compensation Reference Signal In The 5G Systems,” and claims priority under 35 U.S.C. § 119(e) to United States Provisional Patent Application Serial Number 62/336,383 filed May 13, 2016 and entitled “UL Phase Compensation Reference Signal In The 5G Systems,” claims priority under 35 U.S.C. § 119(e) to United States Provisional Patent Application Serial Number 62/344,101 filed June 1, 2016 and entitled “Dual Phase Compensation Reference Signal Transmission And Port Mapping In The 5G Systems,” which are herein incorporated by reference in their entirety.

BACKGROUND

[0002] A variety of wireless cellular communication systems have been implemented, including a 3rd Generation Partnership Project (3GPP) Universal Mobile Telecommunications System, a 3GPP Long-Term Evolution (LTE) system, and a 3GPP LTE-Advanced (LTE-A) system. Next-generation wireless cellular communication systems based upon LTE and LTE-A systems are being developed, such as a fifth generation (5G) wireless system / 5G mobile networks system. Next-generation wireless cellular communication systems may provide support for higher bandwidths in part by supporting higher carrier frequencies, such as centimeter-wave and millimeter-wave frequencies.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The embodiments of the disclosure will be understood more fully from the detailed description given below and from the accompanying drawings of various embodiments of the disclosure. However, while the drawings are to aid in explanation and understanding, they are only an aid, and should not be taken to limit the disclosure to the specific embodiments depicted therein.

[0004] **Fig. 1** illustrates example subframe configurations, in accordance with some embodiments of the disclosure.

[0005] **Fig. 2** illustrates an example pattern of Downlink (DL) Phase Compensation Reference Signal (PCRS) transmission across a four Physical Resource Block (PRB) allocation, in accordance with some embodiments of the disclosure.

[0006] **Fig. 3** illustrates an example pattern of DL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0007] **Fig. 4** illustrates an example pattern of PCRS transmission and Demodulation Reference Signal (DMRS) transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0008] **Fig. 5** illustrates an example pattern of DL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0009] **Fig. 6** illustrates an example pattern of Uplink (UL) PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0010] **Fig. 7** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0011] **Fig. 8** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0012] **Fig. 9** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0013] **Fig. 10** illustrates an example pattern of DL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0014] **Fig. 11** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0015] **Fig. 12** illustrates an example pattern of PCRS transmission and DMRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0016] **Figs. 13A to 13B** illustrate an example pattern of PCRS transmission and DMRS transmission across two four-PRB allocations, in accordance with some embodiments of the disclosure.

[0017] **Fig. 14** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0018] **Fig. 15** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0019] **Fig. 16** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0020] **Fig. 17** illustrates an example pattern of DL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0021] **Fig. 18** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0022] **Fig. 19** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0023] **Fig. 20** illustrates an example pattern of DL DMRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure.

[0024] **Fig. 21** illustrates an Evolved Node B (eNB) and a User Equipment (UE), in accordance with some embodiments of the disclosure.

[0025] **Fig. 22** illustrates hardware processing circuitries for an eNB for PCRS, in accordance with some embodiments of the disclosure.

[0026] **Fig. 23** illustrates hardware processing circuitries for a UE for PCRS, in accordance with some embodiments of the disclosure.

[0027] **Figs. 24-26** illustrate methods for an eNB for PCRS, in accordance with some embodiments of the disclosure.

[0028] **Figs. 27-29** illustrate methods for a UE for PCRS, in accordance with some embodiments of the disclosure.

[0029] **Fig. 30** illustrates example components of a UE device, in accordance with some embodiments of the disclosure.

DETAILED DESCRIPTION

[0030] Various wireless cellular communication systems have been implemented or are being proposed, including a 3rd Generation Partnership Project (3GPP) Universal Mobile Telecommunications System (UMTS), a 3GPP Long-Term Evolution (LTE) system, a 3GPP LTE-Advanced system, and a 5th Generation wireless system / 5th Generation mobile networks (5G) system / 5th Generation new radio (NR) system.

[0031] Some proposed cellular communication systems may incorporate radio frequencies including one or more frequency bands between 30 gigahertz (GHz) and 300 GHz. Corresponding with radio wavelengths from 10 millimeter (mm) to 1 mm, such communication systems may sometimes be referred to as millimeter-wave (mmWave) systems.

[0032] 5G systems may accordingly work at mmWave frequencies, which may in turn support data rates of 30 gigabits per second (Gbps). In comparison with legacy LTE communication systems, 5G systems may operate in frequency bands that may be ten times higher. 5G systems may be disposed to employ larger subcarrier spacing in Orthogonal

Frequency-Division Multiplexing (OFDM) arrangements in order to avoid frequency-domain offsets.

[0033] Phase noise may be a kind of frequency offset (or offset in the frequency domain) generated in an oscillator through a Voltage-Controlled Oscillator (VCO) circuitry, a Phase-Locked Loop (PLL) circuitry, or both. In a communication system structured to have various subcarrier frequencies, phase noise may induce inter-carrier interference. Phase noise may advantageously be compensated.

[0034] Disclosed herein are various mechanisms and methods for implementing reference signals to compensate for impacts due to phase noise (e.g. inter-carrier interference). Such reference signals may be termed Phase-noise Compensation Reference Signals (PCRS).

[0035] In the following description, numerous details are discussed to provide a more thorough explanation of embodiments of the present disclosure. It will be apparent to one skilled in the art, however, that embodiments of the present disclosure may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring embodiments of the present disclosure.

[0036] Note that in the corresponding drawings of the embodiments, signals are represented with lines. Some lines may be thicker, to indicate a greater number of constituent signal paths, and/or have arrows at one or more ends, to indicate a direction of information flow. Such indications are not intended to be limiting. Rather, the lines are used in connection with one or more exemplary embodiments to facilitate easier understanding of a circuit or a logical unit. Any represented signal, as dictated by design needs or preferences, may actually comprise one or more signals that may travel in either direction and may be implemented with any suitable type of signal scheme.

[0037] Throughout the specification, and in the claims, the term "connected" means a direct electrical, mechanical, or magnetic connection between the things that are connected, without any intermediary devices. The term "coupled" means either a direct electrical, mechanical, or magnetic connection between the things that are connected or an indirect connection through one or more passive or active intermediary devices. The term "circuit" or "module" may refer to one or more passive and/or active components that are arranged to cooperate with one another to provide a desired function. The term "signal" may refer to at least one current signal, voltage signal, magnetic signal, or data/clock signal. The meaning of "a," "an," and "the" include plural references. The meaning of "in" includes "in" and "on."

[0038] The terms "substantially," "close," "approximately," "near," and "about" generally refer to being within +/- 10% of a target value. Unless otherwise specified the use of the ordinal adjectives "first," "second," and "third," etc., to describe a common object, merely indicate that different instances of like objects are being referred to, and are not intended to imply that the objects so described must be in a given sequence, either temporally, spatially, in ranking, or in any other manner.

[0039] It is to be understood that the terms so used are interchangeable under appropriate circumstances such that the embodiments of the invention described herein are, for example, capable of operation in other orientations than those illustrated or otherwise described herein.

[0040] The terms "left," "right," "front," "back," "top," "bottom," "over," "under," and the like in the description and in the claims, if any, are used for descriptive purposes and not necessarily for describing permanent relative positions.

[0041] For purposes of the embodiments, the transistors in various circuits, modules, and logic blocks are Tunneling FETs (TFETs). Some transistors of various embodiments may comprise metal oxide semiconductor (MOS) transistors, which include drain, source, gate, and bulk terminals. The transistors may also include Tri-Gate and FinFET transistors, Gate All Around Cylindrical Transistors, Square Wire, or Rectangular Ribbon Transistors or other devices implementing transistor functionality like carbon nanotubes or spintronic devices. MOSFET symmetrical source and drain terminals i.e., are identical terminals and are interchangeably used here. A TFET device, on the other hand, has asymmetric Source and Drain terminals. Those skilled in the art will appreciate that other transistors, for example, Bi-polar junction transistors-BJT PNP/NPN, BiCMOS, CMOS, etc., may be used for some transistors without departing from the scope of the disclosure.

[0042] For the purposes of the present disclosure, the phrases "A and/or B" and "A or B" mean (A), (B), or (A and B). For the purposes of the present disclosure, the phrase "A, B, and/or C" means (A), (B), (C), (A and B), (A and C), (B and C), or (A, B and C).

[0043] In addition, the various elements of combinatorial logic and sequential logic discussed in the present disclosure may pertain both to physical structures (such as AND gates, OR gates, or XOR gates), or to synthesized or otherwise optimized collections of devices implementing the logical structures that are Boolean equivalents of the logic under discussion.

[0044] In addition, for purposes of the present disclosure, the term "eNB" may refer to a legacy LTE capable Evolved Node-B (eNB), a next-generation or 5G-capable eNB, an

mmWave eNB, an mmWave small cell, an Access Point (AP), and/or another base station for a wireless communication system. For purposes of the present disclosure, the term “UE” may refer to a legacy LTE UE, a next-generation or 5G-capable UE, an mmWave UE, a station (STA), and/or another mobile equipment for a wireless communication system.

[0045] Various embodiments of eNBs and/or UEs discussed below may process one or more transmissions of various types. Some processing of a transmission may comprise demodulating, decoding, detecting, parsing, and/or otherwise handling a transmission that has been received. In some embodiments, an eNB or UE processing a transmission may determine or recognize the transmission’s type and/or a condition associated with the transmission. For some embodiments, an eNB or UE processing a transmission may act in accordance with the transmission’s type, and/or may act conditionally based upon the transmission’s type. An eNB or UE processing a transmission may also recognize one or more values or fields of data carried by the transmission. Processing a transmission may comprise moving the transmission through one or more layers of a protocol stack (which may be implemented in, e.g., hardware and/or software-configured elements), such as by moving a transmission that has been received by an eNB or a UE through one or more layers of a protocol stack.

[0046] Various embodiments of eNBs and/or UEs discussed below may also generate one or more transmissions of various types. Some generating of a transmission may comprise modulating, encoding, formatting, assembling, and/or otherwise handling a transmission that is to be transmitted. In some embodiments, an eNB or UE generating a transmission may establish the transmission’s type and/or a condition associated with the transmission. For some embodiments, an eNB or UE generating a transmission may act in accordance with the transmission’s type, and/or may act conditionally based upon the transmission’s type. An eNB or UE generating a transmission may also determine one or more values or fields of data carried by the transmission. Generating a transmission may comprise moving the transmission through one or more layers of a protocol stack (which may be implemented in, e.g., hardware and/or software-configured elements), such as by moving a transmission to be sent by an eNB or a UE through one or more layers of a protocol stack.

[0047] Phase noise may compensation may be frequency-domain compensation or time-domain compensation (or both). Under some time-domain methods, a known signal (which may be a PCRS signal) may be sent in multiple symbols on a transmission-side of a wireless communication link. On the receive-side of the wireless communication link, a phase difference between symbols may be determined, and the phase difference may be

corrected to compensate for the phase noise. PCRS may advantageously improve performance of systems having data encoded at high modulation and/or high coding rates.

[0048] **Fig. 1** illustrates example subframe configurations, in accordance with some embodiments of the disclosure. A scenario 100 may comprise one or more subframe configurations 110, each of which may span a number of symbols 120. As depicted, scenario 100 comprises nine subframe configurations (enumerated 0 through 8), each of which spans fourteen symbols (spanning symbol indices 0 through 13). Subframe configurations 0 through 8 may be employed in 5G and/or mmWave systems and may support PCRS.

[0049] A subframe may be configured to carry a Downlink (DL) control channel (e.g., “Dc,” such as a 5G Physical Downlink Control Channel (xPDCCH)) in one or more initial symbols (e.g., symbol 0, or symbols 0 and 1). A DL control channel may specify a subframe configuration in a first symbol of a subframe, and may thereby determine the configuration of the remaining symbols of the subframe. In some embodiments, subframes may be configured by DL control channels on a subframe-by-subframe basis.

[0050] In some embodiments, a subframe may be configured to carry a DL data channel (e.g., “Dd,” such as a 5G Physical Downlink Shared Channel (xPDSCH)) in one or more symbols subsequent to the one or more initial symbols (e.g., starting from symbol 1 or 2 and extending through symbol 11 or 13). Such subframe configurations may be DL subframe configurations, and may provide for DL data transmission.

[0051] For some embodiments, a subframe may be configured to carry a gap period (GP) in one or more symbols subsequent to the one or more initial symbols (e.g., symbol 1 and/or symbol 12). A GP may provide time for a transceiver to transition from a transmission mode to a receive mode, or may provide time for a transceiver to transition from a receive mode to a transmission mode. In some embodiments, a subframe may be configured to carry an Uplink (UL) data channel (e.g., “Ud,” such as a 5G Physical Uplink Shared Channel (xPDSCH)) in one or more symbols subsequent to the initial symbols and/or the gap periods (e.g., starting from symbol 2 and extending through symbol 11, 13, or 13). Such subframe configurations may be UL subframe configurations, and may provide for UL data transmission.

[0052] In some embodiments, a subframe may be configured to carry a UL control channel (e.g., “Uc,” such as a 5G Physical Uplink Control Channel (PUCCH)) in one or more symbols (e.g., in symbol 13). For some embodiments, a subframe may be configured to carry a Channel State Information Reference Signal (CSI-RS) in one or more symbols (e.g., in

symbol 12 and/or 13). In some embodiments, a subframe may be configured to carry a Sounding Reference Signal (SRS) in one or more symbols (e.g., in symbol 12 and/or 13).

[0053] Subframe configurations 0 through 3 may be DL subframe configurations, and may carry a DL control channel in symbol 0 and a DL data channel in symbols 2 through 11. Subframe configuration 0 may additionally carry a DL data channel in symbol 1, and either a DL data channel or a CSI-RS in symbols 12 and 13. Subframe configuration 1 may additionally carry a DL data channel in symbol 1, a GP in symbol 12, and either a UL control channel or an SRS in symbol 13. Subframe configuration 2 may additionally carry a DL control channel in symbol 1, and either a DL data channel or a CSI-RS in symbols 12 and 13. Subframe configuration 3 may additionally carry a DL control channel in symbol 1, a GP in symbol 12, and either a UL control channel or an SRS in symbol 13.

[0054] Subframe configurations 4 through 8 may be UL subframe configurations, and may carry a DL control channel in symbol 0, a GP in symbol 1, and a UL data channel in symbols 2 through 11. Subframe configuration 4 may additionally carry a UL data channel in symbols 12 and 13. Subframe configuration 5 may additionally carry a UL data channel in symbol 12 and either a UL control channel or an SRS in symbol 13. Subframe configuration 6 may additionally carry a UL data channel in symbol 12 and a CSI-RS in symbol 13. Subframe configuration 7 may additionally carry an SRS in symbol 12 and a CSI-RS in symbol 13. Subframe configuration 8 may additionally carry an SRS in symbol 12 and a UL control channel in symbol 13.

[0055] In various subframe configurations, PCRS may be positioned in symbols carrying data (e.g., xPDSCH and/or xPUSCH). Some embodiments may employ commonality of PCRS patterns in DL and UL. Some embodiments may employ symmetry in the frequency domain

[0056] For various subframe configurations, PCRS may have a pattern within a resource allocation comprising four Physical Resource Blocks (PRBs). Each four-PRB allocation may comprise 48 allocated subcarrier frequencies. In some embodiments, a four-PRB allocation may

[0057] **Fig. 2** illustrates an example pattern of Downlink (DL) Phase Compensation Reference Signal (PCRS) transmission across a four Physical Resource Block (PRB) allocation, in accordance with some embodiments of the disclosure. A pattern 200 may comprise four PRBs 201 spanning a four-PRB allocation 204. Pattern 200 may comprise a first PCRS sequence 210 carrying PCRS and a second PCRS sequence 220 carrying PCRS.

[0058] PRBs 201 may be substantially similar to legacy LTE PRBs and may accordingly span 14 OFDM symbols and 12 subcarrier frequencies, and four-PRB allocation 204 may accordingly span 14 OFDM symbols and 48 subcarrier frequencies. Four-PRB allocation 204 may comprise Resource Elements (REs) spanning the 14 OFDM symbols and the 48 subcarrier frequencies. In some embodiments, PRBs 201 may span other numbers of OFDM symbols and/or other numbers of subcarrier frequencies. Pattern 200 may repeat in frequency (e.g., every four PRBs across a system bandwidth).

[0059] First PCRS sequence 210 and second PCRS sequence 220 may span OFDM symbols 3 through 13. In some embodiments, first PCRS sequence 210 and/or second PCRS sequence 220 may span other OFDM symbols.

[0060] For some embodiments, the OFDM symbols that a PCRS sequence spans may be related to symbols carrying data in a corresponding subframe configuration. For example, first PCRS sequence 210 and second PCRS sequence 220 may correspond with configuration 0 and/or configuration 2 of subframe configurations 110. For some embodiments, the initial symbol (e.g., symbol 3) may commonly be an initial symbol for data transmission for both DL transmission and UL transmission. In some embodiments, the selection of PCRS and the option to use for data or PCRS may be configured by Radio Resource Control (RRC) signaling, or may be configured by Downlink Control Information (DCI) configuration.

[0061] Each port may be allocated to xPDSCH transmission, and may be associated with different transmission points (TPs). In some embodiments, one eNB may implement multiple TPs. In some embodiments, pattern 200 may apply to DL transmissions (although pattern 200 may apply to UL transmissions in some embodiments). In pattern 200, data may be transmitted starting on either symbol 1 or 2, and ending on symbol 11 or 13. In some embodiments, for one TP, one symbol allocated for PCRS may be used for data transmission.

[0062] First PCRS sequence 210 may be carried at a first subcarrier frequency within four-PRB allocation 204, and may correspond with a first antenna port. Second PCRS sequence 220 may be carried at a second subcarrier frequency within four-PRB allocation 204, and may correspond with a second antenna port.

[0063] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially evenly across the 48 subcarrier frequencies of four-PRB allocation 204. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 16 within four-PRB allocation 204, and the second subcarrier frequency may be a subcarrier 31 within four-PRB allocation 204. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[0064] In some embodiments, the first antenna port may be an antenna port 61, and the second antenna port may be an antenna port 60. In various embodiments, the first antenna port and/or the second antenna port may be other antenna ports.

[0065] **Fig. 3** illustrates an example pattern of DL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 300 may comprise four PRBs 301 spanning a four-PRB allocation 304. Pattern 300 may comprise a first PCRS sequence 310 carrying PCRS and a second PCRS sequence 320 carrying PCRS. First PCRS sequence 310 may be carried at a first subcarrier frequency within four-PRB allocation 304, and may correspond with a first antenna port. Second PCRS sequence 320 may be carried at a second subcarrier frequency within four-PRB allocation 304, and may correspond with a second antenna port. In various embodiments, pattern 300 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 300 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[0066] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially about a center of the 48 subcarrier frequencies of four-PRB allocation 304, which may advantageously address a potentially higher Inter-Carrier Interference (ICI) that may exist at a center of four-PRB allocation 304. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 23 within four-PRB allocation 304, and the second subcarrier frequency may be a subcarrier 24 within four-PRB allocation 304. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[0067] In some embodiments, the first antenna port may be antenna port 61, and the second antenna port may be an antenna port 60. In various embodiments, the first antenna port and/or the second antenna port may be other antenna ports.

[0068] **Fig. 4** illustrates an example pattern of PCRS transmission and Demodulation Reference Signal (DMRS) transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 400 may comprise four PRBs 401 spanning a four-PRB allocation 404. Pattern 400 may comprise a first PCRS sequence 410 carrying PCRS and a second PCRS sequence 420 carrying PCRS. First PCRS sequence 410 may be carried at a first subcarrier frequency within four-PRB allocation 404, and may correspond with a first antenna port. Second PCRS sequence 420 may be carried at a second subcarrier frequency within four-PRB allocation 404, and may correspond with a second antenna port. In various embodiments, pattern 400 may be substantially similar to pattern 200 (and/or other

patterns disclosed herein), and the elements of pattern 400 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[0069] Pattern 400 may also comprise a DMRS sequence 490 spanning 48 subcarrier frequencies in OFDM symbol 2. In some embodiments, DMRS sequence 490 in subcarrier frequency 0 may correspond with one of an antenna port 10 or an antenna port 20 or an antenna port 40. For some embodiments, DMRS sequence 490 in subcarrier frequency 1 may correspond with one of an antenna port 21 or an antenna port 41. In some embodiments, DMRS sequence 490 in subcarrier frequency 2 may correspond with an antenna port 42. For some embodiments, DMRS sequence 490 in subcarrier frequency 3 may correspond with an antenna port 43. The correspondence between antenna ports and DMRS sequence 490 in subcarrier frequencies 0 through 3 may repeat every 4 subcarrier frequencies. In various embodiments, DMRS sequence 490 in subcarrier frequencies 0 through 47 may correspond otherwise with various antenna ports.

[0070] In some embodiments, the first subcarrier frequency may be a subcarrier frequency 16 within four-PRB allocation 404, and the second subcarrier frequency may be a subcarrier 31 within four-PRB allocation 404. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[0071] For some embodiments, the first antenna port may be one of antenna port 10 or antenna port 20 or antenna port 40, and the second antenna port may be antenna port 43. In various embodiments, the first antenna port and/or the second antenna port may be antenna ports other than antenna ports 10, 20, or 40 and antenna port 43. For example, the first antenna port or the second antenna port may be one of antenna port 21 or antenna port 41, or may be antenna port 42. In various embodiments, the first antenna port and/or the second antenna port may be other antenna ports.

[0072] For various embodiments, first PCRS sequence 410 may correspond with the same antenna port as DMRS sequence 490 at the first subcarrier frequency, and second PCRS sequence 420 may correspond with the same antenna port as DMRS sequence 490 at the second subcarrier frequency. In some embodiments, first PCRS sequence 410 and second PCRS sequence 420 may reuse one or more DMRS signals used at those subcarrier frequencies. One or more PCRS signals may accordingly be generated in a manner linked with one or more respectively corresponding DMRS signals at the same subcarrier frequencies.

[0073] For DL transmission, first PCRS sequence 410 may correspond to PCRS for a first TP and second PCRS sequence 420 may correspond to PCRS for a second TP. For UL

transmission, first PCRS sequence 410 may correspond to PCRS for a first UE, and second PCRS sequence 420 may correspond to PCRS for a second UE.

[0074] **Fig. 5** illustrates an example pattern of DL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 500 may comprise four PRBs 501 spanning a four-PRB allocation 504. Pattern 500 may comprise a first PCRS sequence 510 carrying PCRS and a second PCRS sequence 520 carrying PCRS. First PCRS sequence 510 may be carried at a first subcarrier frequency within four-PRB allocation 504, and may correspond with a first antenna port. Second PCRS sequence 520 may be carried at a second subcarrier frequency within four-PRB allocation 504, and may correspond with a second antenna port. In various embodiments, pattern 500 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 500 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[0075] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially evenly across the 48 subcarrier frequencies of four-PRB allocation 504. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 16 within four-PRB allocation 504, and the second subcarrier frequency may be a subcarrier 32 within four-PRB allocation 504. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[0076] In some embodiments, the first antenna port may be an antenna port 61, and the second antenna port may be an antenna port 60. In various embodiments, the first antenna port and/or the second antenna port may be other antenna ports.

[0077] The first subcarrier frequency and the second subcarrier frequency may accordingly be located in identical DMRS antenna port positions (e.g., at subcarrier frequencies having indexes separated by 16, or by another multiple of 4). For example, in some embodiments, the first subcarrier frequency may be located at a subcarrier frequency 15 and the second subcarrier frequency 31. In another example, the first subcarrier frequency may be located at a subcarrier frequency 17 and the second subcarrier frequency may be located at a subcarrier frequency 33. For some such embodiments, a PCRS signal may effectively be started from symbol index 2 (instead of from symbol index 3).

[0078] In pattern 200, pattern 300, pattern 400, and/or pattern 500, an initial symbol of PCRS may be symbol 1 (e.g., for configuration 2 or for configuration 3 of subframe configurations 110). For UL transmission, separate users (e.g., separate UEs) may have one or more separate PCRS REs to track frequency offsets in separate oscillators. Additional

PCRS REs (e.g., additional PCRS sequences) may support four UL Multi-User Multiple Input Multiple Output (MU-MIMO). For example, additional REs may be located in a substantially equally-distributed manner.

[0079] **Fig. 6** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 600 may comprise four PRBs 601 spanning a four-PRB allocation 604. Pattern 600 may comprise a first PCRS sequence 610 carrying PCRS, a second PCRS sequence 620 carrying PCRS, a third PCRS sequence 630 carrying PCRS, and a fourth PCRS sequence 640 carrying PCRS. First PCRS sequence 610 may be carried at a first subcarrier frequency within four-PRB allocation 604, and may correspond with a first antenna port. Second PCRS sequence 620 may be carried at a second subcarrier frequency within four-PRB allocation 604, and may correspond with a second antenna port. Third PCRS sequence 630 may be carried at a third subcarrier frequency within four-PRB allocation 604, and may correspond with a third antenna port. Fourth PCRS sequence 640 may be carried at a fourth subcarrier frequency within four-PRB allocation 604, and may correspond with a fourth antenna port. In various embodiments, pattern 600 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 600 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[0080] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be spaced in four-PRB allocation 604 substantially evenly between a subcarrier frequency 0, a central subcarrier frequency (e.g., a subcarrier frequency 23), and themselves. For various embodiments, the third subcarrier frequency and the fourth subcarrier frequency may be spaced substantially evenly between a central subcarrier frequency (e.g., a subcarrier frequency 24), a subcarrier frequency 47, and themselves. The first subcarrier frequency, the second subcarrier frequency, the third subcarrier frequency, and the fourth subcarrier frequency may be spaced in four-PRB allocation 604 in a substantially equally-distributed manner.

[0081] In some embodiments, the first subcarrier frequency may be a subcarrier frequency 7, the second subcarrier frequency may be a subcarrier frequency 16, the third subcarrier frequency may be a subcarrier frequency 31, and the fourth subcarrier frequency may be a subcarrier frequency 40. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[0082] In some embodiments, the first antenna port may be an antenna port 53, the second antenna port may be an antenna port 51, the third antenna port may be an antenna port

50, and the fourth antenna port may be an antenna port 52. In various embodiments, the first antenna port, second antenna port, third antenna port, and/or fourth antenna port may be antenna ports other than antenna port 51, antenna port 50, antenna port 52, and antenna port 53. In various embodiments, the first antenna port, the second antenna port, the third antenna port, and/or the fourth antenna port may be other antenna ports.

[0083] **Fig. 7** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 700 may comprise four PRBs 701 spanning a four-PRB allocation 704. Pattern 700 may comprise a first PCRS sequence 710 carrying PCRS, a second PCRS sequence 720 carrying PCRS, a third PCRS sequence 730 carrying PCRS, and a fourth PCRS sequence 740 carrying PCRS. First PCRS sequence 710 may be carried at a first subcarrier frequency within four-PRB allocation 704, and may correspond with a first antenna port. Second PCRS sequence 720 may be carried at a second subcarrier frequency within four-PRB allocation 704, and may correspond with a second antenna port. Third PCRS sequence 730 may be carried at a third subcarrier frequency within four-PRB allocation 704, and may correspond with a third antenna port. Fourth PCRS sequence 740 may be carried at a fourth subcarrier frequency within four-PRB allocation 704, and may correspond with a fourth antenna port. In various embodiments, pattern 700 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 700 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[0084] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be spaced in four-PRB allocation 704 substantially evenly between a subcarrier frequency 0, a central subcarrier frequency (e.g., a subcarrier frequency 23), and themselves. For various embodiments, the third subcarrier frequency and the fourth subcarrier frequency may be spaced substantially evenly between a central subcarrier frequency (e.g., a subcarrier frequency 24), a subcarrier frequency 47, and themselves. The first subcarrier frequency, the second subcarrier frequency, the third subcarrier frequency, and the fourth subcarrier frequency may be spaced in four-PRB allocation 704 in a substantially equally-distributed manner.

[0085] In some embodiments, the first subcarrier frequency may be a subcarrier frequency 8, the second subcarrier frequency may be a subcarrier frequency 16, the third subcarrier frequency may be a subcarrier frequency 31, and the fourth subcarrier frequency may be a subcarrier frequency 39. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[0086] In some embodiments, the first antenna port may be an antenna port 53, the second antenna port may be an antenna port 51, the third antenna port may be an antenna port 50, and the fourth antenna port may be an antenna port 52. In various embodiments, the first antenna port, second antenna port, third antenna port, and/or fourth antenna port may be other antenna ports.

[0087] **Fig. 8** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 800 may comprise four PRBs 801 spanning a four-PRB allocation 804. Pattern 800 may comprise a first PCRS sequence 810 carrying PCRS, a second PCRS sequence 820 carrying PCRS, a third PCRS sequence 830 carrying PCRS, and a fourth PCRS sequence 840 carrying PCRS. First PCRS sequence 810 may be carried at a first subcarrier frequency within four-PRB allocation 804, and may correspond with a first antenna port. Second PCRS sequence 820 may be carried at a second subcarrier frequency within four-PRB allocation 804, and may correspond with a second antenna port. Third PCRS sequence 830 may be carried at a third subcarrier frequency within four-PRB allocation 804, and may correspond with a third antenna port. Fourth PCRS sequence 840 may be carried at a fourth subcarrier frequency within four-PRB allocation 804, and may correspond with a fourth antenna port. In various embodiments, pattern 800 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 800 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[0088] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be spaced in four-PRB allocation 804 substantially evenly between a subcarrier frequency 0, a central subcarrier frequency (e.g., a subcarrier frequency 23), and themselves. For various embodiments, the third subcarrier frequency and the fourth subcarrier frequency may be spaced substantially evenly between a central subcarrier frequency (e.g., a subcarrier frequency 24), a subcarrier frequency 47, and themselves. The first subcarrier frequency, the second subcarrier frequency, the third subcarrier frequency, and the fourth subcarrier frequency may be spaced in four-PRB allocation 804 in a substantially equally-distributed manner.

[0089] In some embodiments, the first subcarrier frequency may be a subcarrier frequency 8, the second subcarrier frequency may be a subcarrier frequency 16, the third subcarrier frequency may be a subcarrier frequency 32, and the fourth subcarrier frequency may be a subcarrier frequency 40. (Accordingly, in various embodiments, the first subcarrier frequency may be a subcarrier frequency 7 or 8, the second subcarrier frequency may be a

subcarrier frequency 15 or 16, the third subcarrier frequency may be a subcarrier frequency 31 or 32, and the fourth subcarrier frequency may be a subcarrier frequency 39 or 40.) For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[0090] In some embodiments, the first antenna port may be an antenna port 53, the second antenna port may be an antenna port 51, the third antenna port may be an antenna port 50, and the fourth antenna port may be an antenna port 52. In various embodiments, the first antenna port, second antenna port, third antenna port, and/or fourth antenna port may be other antenna ports.

[0091] **Fig. 9** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 900 may comprise four PRBs 901 spanning a four-PRB allocation 904. Pattern 900 may comprise a first PCRS sequence 910 carrying PCRS, a second PCRS sequence 920 carrying PCRS, a third PCRS sequence 930 carrying PCRS, and a fourth PCRS sequence 940 carrying PCRS. First PCRS sequence 910 may be carried at a first subcarrier frequency within four-PRB allocation 904, and may correspond with a first antenna port. Second PCRS sequence 920 may be carried at a second subcarrier frequency within four-PRB allocation 904, and may correspond with a second antenna port. Third PCRS sequence 930 may be carried at a third subcarrier frequency within four-PRB allocation 904, and may correspond with a third antenna port. Fourth PCRS sequence 940 may be carried at a fourth subcarrier frequency within four-PRB allocation 904, and may correspond with a fourth antenna port. In various embodiments, pattern 900 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 900 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[0092] In various embodiments, the first subcarrier frequency may be distributed substantially evenly between a subcarrier frequency 0 and a central subcarrier frequency (e.g., a subcarrier frequency 23) of four-PRB allocation 904; the second subcarrier frequency and the third subcarrier frequency may be distributed substantially about a center of the 48 subcarrier frequencies of four-PRB allocation 904; and the fourth subcarrier frequency may be distributed substantially evenly between a central subcarrier frequency (e.g., a subcarrier frequency 24) and a subcarrier frequency 47 of four-PRB allocation 904. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 11, the second subcarrier frequency may be a subcarrier frequency 23, the third subcarrier frequency may be a subcarrier frequency 24, and the fourth subcarrier frequency may be a subcarrier frequency

36. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[0093] In some embodiments, the first antenna port may be an antenna port 53, the second antenna port may be an antenna port 51, the third antenna port may be an antenna port 50, and the fourth antenna port may be an antenna port 52. In various embodiments, the first antenna port, second antenna port, third antenna port, and/or fourth antenna port may be other antenna ports.

[0094] As discussed herein, DL transmissions may carry PCRS (which may include phase-noise compensation reference signals). **Fig. 10** illustrates an example pattern of DL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 1000 may comprise four PRBs 1001 spanning a four-PRB allocation 1004. Pattern 1000 may comprise a first PCRS sequence 1010 carrying PCRS and a second PCRS sequence 1020 carrying PCRS. First PCRS sequence 1010 may be carried at a first subcarrier frequency within four-PRB allocation 1004, and may correspond with a first antenna port. Second PCRS sequence 1020 may be carried at a second subcarrier frequency within four-PRB allocation 1004, and may correspond with a second antenna port. In various embodiments, pattern 1000 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 1000 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[0095] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially evenly across the 48 subcarrier frequencies of four-PRB allocation 1004. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 16 within four-PRB allocation 1004, and the second subcarrier frequency may be a subcarrier 31 within four-PRB allocation 1004. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[0096] In some embodiments, the first antenna port may be an antenna port 61, and the second antenna port may be an antenna port 60. In various embodiments, the first antenna port and/or the second antenna port may be other antenna ports.

[0097] In various embodiments, DL PCRS may be associated with xPDSCH transmissions. In some embodiments, DL PCRS may be transmitted on an antenna port $p = 60$ and an antenna port $p = 61$. For some embodiments, DL PCRS may be present and may be a valid reference for phase noise compensation, such as if an xPDSCH transmission is associated with the corresponding antenna port. In some embodiments, DL PCRS may be

transmitted on PRBs and symbols (e.g., in REs) upon which a corresponding xPDSCH is mapped. For some embodiments, DL PCRS may be identical in a plurality of symbols (up to and including all symbols) corresponding to an xPDSCH allocation.

[0098] For antenna ports $p \in \{60, 61\}$, in a PRB having a frequency-domain index n_{PRB} assigned for a corresponding xPDSCH transmission, a DMRS $a_{k,l}^{(p'),DMRS}$ associated with the xPDSCH may be disposed to being mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ for a plurality of xPDSCH symbols in a subframe (up to and including all xPDSCH symbols) according to the following equation:

$$a_{k,l}^{(p)} = a_{k,2}^{(p')DMRS}$$

In the equation, p' may be a DMRS port number associated with the xPDSCH transmission.

[0099] A starting resource block number of an xPDSCH physical resource allocation n_{PRB}^{xPDSCH} in the frequency domain, a resource allocation bandwidth in terms of a number of resource blocks N_{PRB}^{xPDSCH} , and resource elements (k, l) in a subframe may be given by the following equations:

$$k = N_{sc}^{RB} \cdot (n_{PRB}^{xPDSCH} + \lfloor m' / 4 \rfloor \cdot 4) + k'$$

$$k' = \begin{cases} 16 & p \in 60 \\ 31 & p \in 61 \end{cases}$$

$$l' = \begin{cases} 1, 3, 4, \dots, 13 & \text{if Subframe configuration} = 0 \\ 1, 3, 4, \dots, 11 & \text{if Subframe configuration} = 1 \\ 3, 4, \dots, 13 & \text{if Subframe configuration} = 2 \\ 3, 4, \dots, 11 & \text{if Subframe configuration} = 3 \end{cases}$$

$$m' = 0, 1, 2, \dots, N_{PRB}^{xPDSCH} - 1$$

In the equations, k may be an index corresponding with subcarrier position (e.g., a subcarrier frequency or a subcarrier frequency index), l' may be a symbol index within a subframe, and m' may be a PRB index.

[00100] For subframe configurations 1 and 3 of subframe configurations 110, PCRS might not be transmitted in the last two symbols if CSI-RS are presented in those symbols.

[00101] Resource elements (k, l) may be used for transmission of UE-specific PCRS on any of the antenna ports in a set S , where $S = \{60\}$ and $S = \{61\}$ might not be used for transmission of xPDSCH on any antenna port in the same subframe.

[00102] For some embodiments, four-PRB allocation 1004 may comprise REs used for PCRS for antenna port 60 and antenna port 61 when xPDSCH is transmitted from $l'=3$ to $l'=13$.

[00103] As discussed herein, DL transmissions may carry PCRS (which may include phase-noise compensation reference signals). **Fig. 11** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 1100 may comprise four PRBs 1101 spanning a four-PRB allocation 1104. Pattern 1100 may comprise a first PCRS sequence 1110 carrying PCRS and a second PCRS sequence 1120 carrying PCRS. First PCRS sequence 1110 may be carried at a first subcarrier frequency within four-PRB allocation 1104, and may correspond with a first antenna port. Second PCRS sequence 1120 may be carried at a second subcarrier frequency within four-PRB allocation 1104, and may correspond with a second antenna port. In various embodiments, pattern 1100 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 1100 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[00104] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially evenly across the 48 subcarrier frequencies of four-PRB allocation 1104. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 16 within four-PRB allocation 1104, and the second subcarrier frequency may be a subcarrier 31 within four-PRB allocation 1104. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[00105] In some embodiments, the first antenna port may be an antenna port 51, and the second antenna port may be an antenna port 50. In various embodiments, the first antenna port and/or the second antenna port may be other antenna ports.

[00106] In various embodiments, UL PCRS may be associated with xPUSCH transmissions. In some embodiments, UL PCRS may be transmitted on an antenna port assigned to a UE. For some embodiments, UL PCRS may be present and may be a valid reference for phase noise compensation, such as if an xPUSCH transmission is associated with the corresponding antenna port. In some embodiments, UL PCRS may be transmitted on PRBs and symbols (e.g., in REs) upon which a corresponding xPUSCH is mapped. For some embodiments, UL PCRS may be identical in a plurality of symbols (up to and including all symbols) corresponding to an xPUSCH allocation.

[00107] For antenna ports $p \in \{50, 51\}$, in a PRB having a frequency-domain index n_{PRB} assigned for a corresponding xPUSCH transmission, a DMRS $a_{k,l}^{(p),DMRS}$ associated with the xPUSCH may be disposed to being mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ for a plurality of xPUSCH symbols in a subframe (up to and including all xPUSCH symbols) according to the following equation:

$$a_{k,l}^{(p)} = a_{k,2}^{(p),DMRS}$$

In the equation, p may be a DMRS port number associated with the xPUSCH transmission.

[00108] A starting resource block number of an xPUSCH physical resource allocation n_{PRB}^{xPUSCH} in the frequency domain, a resource allocation bandwidth in terms of a number of resource blocks N_{PRB}^{xPUSCH} , and resource elements (k, l) in a subframe may be given by the following equations:

$$\begin{aligned} k &= N_{sc}^{RB} \cdot (n_{PRB}^{xPUSCH} + \lfloor m' / 4 \rfloor \cdot 4) + k' \\ k' &= \begin{cases} 16 & p \in 50 \\ 31 & p \in 51 \end{cases} \\ l' &= \begin{cases} 3, \dots, 13, & \text{if Subframeconfiguration} = 4 \\ 3, \dots, 12, & \text{if Subframeconfiguration} = 5 \text{ or } 6 \\ 3, \dots, 11, & \text{if Subframeconfiguration} = 7 \text{ or } 8 \end{cases} \\ m' &= 0, 1, 2, \dots, N_{PRB}^{xPUSCH} - 1 \end{aligned}$$

In the equations, k may be an index corresponding with subcarrier position (e.g., a subcarrier frequency or a subcarrier frequency index), l' may be a symbol index within a subframe, and m' may be a PRB index.

[00109] Resource elements (k, l) may be used for transmission of UE-specific PCRS on any of the antenna ports in a set S , where $S = \{50\}$ and $S = \{51\}$ might not be used for transmission of xPUSCH on any antenna port in the same subframe.

[00110] For some embodiments, four-PRB allocation 1104 may comprise REs used for PCRS for antenna port 50 and antenna port 51 when xPUSCH is transmitted from $l' = 3$ to $l' = 13$.

[00111] In various embodiments, another way to support more than two MU-MIMO users may be to multiplex PCRS REs in a Time-Division Multiplexing (TDM) manner. Multiple users may accordingly be multiplexed in a TDM manner. **Fig. 12** illustrates an example pattern of PCRS transmission and DMRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 1200 may comprise four

PRBs 1201 spanning a four-PRB allocation 1204. Pattern 1200 may comprise a first PCRS sequence 1210 carrying PCRS and a second PCRS sequence 1220 carrying PCRS. First PCRS sequence 1210 may be carried at a first subcarrier frequency within four-PRB allocation 1204, and may correspond with a first antenna port and a second antenna port multiplexed in a TDM manner. Second PCRS sequence 1220 may be carried at a second subcarrier frequency within four-PRB allocation 1204, and may correspond with a third antenna port and a fourth antenna port multiplexed in a TDM manner. In various embodiments, pattern 1200 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 1200 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[00112] Pattern 1200 may also comprise a DMRS sequence 1290 spanning 48 subcarrier frequencies in OFDM symbol 2. In some embodiments, DMRS sequence 1290 in subcarrier frequency 0 may correspond with one of an antenna port 10 or an antenna port 20 or an antenna port 40. For some embodiments, DMRS sequence 1290 in subcarrier frequency 1 may correspond with one of an antenna port 21 or an antenna port 41. In some embodiments, DMRS sequence 1290 in subcarrier frequency 2 may correspond with an antenna port 42. For some embodiments, DMRS sequence 1290 in subcarrier frequency 3 may correspond with an antenna port 43. The correspondence between antenna ports and DMRS sequence 1290 in subcarrier frequencies 0 through 3 may repeat every 4 subcarrier frequencies. In various embodiments, DMRS sequence 1290 in subcarrier frequencies 0 through 47 may correspond otherwise with various antenna ports.

[00113] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially evenly across the 48 subcarrier frequencies of four-PRB allocation 1204. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 16 within four-PRB allocation 1204, and the second subcarrier frequency may be a subcarrier 31 within four-PRB allocation 1204. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[00114] In some embodiments, the first antenna port, which may correspond with a first set of REs 1211 in odd OFDM symbols of first PCRS sequence 1210, may be an antenna port 44. The second antenna port, which may correspond with a second set of REs 1212 in even OFDM symbols of first PCRS sequence 1210, may be an antenna port 10 or an antenna port 20 or an antenna port 40. For some embodiments, the third antenna port, which may correspond with a third set of REs 1223 in odd OFDM symbols of second PCRS sequence 1220, may be an antenna port 45. The fourth antenna port, which may correspond with a

fourth set of REs 1224 in even OFDM symbols of second PCRS sequence 1220, may be an antenna port 43. In various embodiments, the first antenna port, the second antenna port, the third antenna port, and/or the fourth antenna port may be other antenna ports.

[00115] Accordingly, second set of REs 1212 (of first PCRS sequence 1210) may correspond with the same antenna port as DMRS sequence 1290 at the first subcarrier frequency, and fourth set of REs 1224 (of the second PCRS sequence 1220) may correspond with the same antenna port as DMRS sequence 1290 at the second subcarrier frequency. In some embodiments, first PCRS sequence 1210 and second PCRS sequence 1220 may reuse one or more DMRS signals at those subcarrier frequencies. One or more PCRS signals may accordingly be generated in a manner linked with one or more respectively corresponding DMRS signals at the same subcarrier frequencies.

[00116] A potential problem of PCRS implementations may be performance degradation for symbols which don't have a PCRS RE for a UL MU-MIMO user. A user may be disposed to calculating an amount of phase rotation from one or more nearest symbols. For example, a User 1 may use symbols 3, 5, 7, 9, 11, and 13 of a PCRS sequence (e.g., at a subcarrier frequency 16 of a four-PRB allocation). In order to estimate a phase rotation of symbol 4, a phase rotation estimate at symbol 3 and/or at symbol 5 may be used. This may result in performance degradation.

[00117] Accordingly, various embodiments may apply a TDM symbol-wise circularity across one or more allocated PRBs (e.g., of a four-PRB allocation). **Figs. 13A to 13B** illustrate an example pattern of PCRS transmission and DMRS transmission across two four-PRB allocations, in accordance with some embodiments of the disclosure. A pattern 1300 may comprise a first four-PRB allocation 1304 and a second four-PRB allocation 1354. In some embodiments, first four-PRB allocation 1304 and second four-PRB allocation 1354 may be adjacent to each other within a wireless spectrum, while in other embodiments, first four-PRB allocation 1304 and second four-PRB allocation 1354 might be adjacent to each other within the wireless spectrum.

[00118] First four-PRB allocation 1304 may comprise four PRBs 1301, and may comprise a first PCRS sequence 1310 carrying PCRS and a second PCRS sequence 1320 carrying PCRS. First PCRS sequence 1310 may be carried at a first subcarrier frequency within first four-PRB allocation 1304, and may correspond with a first antenna port and a second antenna port multiplexed in a TDM manner. Second PCRS sequence 1320 may be carried at a second subcarrier frequency within first four-PRB allocation 1304, and may correspond with a third antenna port and a fourth antenna port multiplexed in a TDM manner.

In various embodiments, first four-PRB allocation 1304 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of first four-PRB allocation 1304 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[00119] Second four-PRB allocation 1354 may comprise four PRBs 1301, and may comprise a third PCRS sequence 1330 carrying PCRS and a fourth PCRS sequence 1340 carrying PCRS. Third PCRS sequence 1330 may be carried at a third subcarrier frequency within second four-PRB allocation 1354, and may correspond with the first antenna port and the second antenna port multiplexed in a TDM manner different from first PCRS sequence 1310. Fourth PCRS sequence 1340 may be carried at a fourth subcarrier frequency within second four-PRB allocation 1354, and may correspond with the third antenna port and the fourth antenna port multiplexed in a TDM manner different from second PCRS sequence 1320. In various embodiments, second four-PRB allocation 1354 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of second four-PRB allocation 1354 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[00120] Pattern 1300 may also comprise a DMRS sequence 1390 spanning 48 subcarrier frequencies of first four-PRB allocation 1304 in OFDM symbol 2, and spanning 48 subcarrier frequencies of second four-PRB allocation 1354 in OFDM symbol 2. In some embodiments, DMRS sequence 1390 in subcarrier frequency 0 (of both first four-PRB allocation 1304 and second four-PRB allocation 1354) may correspond with one of an antenna port 10 or an antenna port 20 or an antenna port 40. For some embodiments, DMRS sequence 1390 in subcarrier frequency 1 (of both first four-PRB allocation 1304 and second four-PRB allocation 1354) may correspond with one of an antenna port 21 or an antenna port 41. In some embodiments, DMRS sequence 1390 in subcarrier frequency 2 (of both first four-PRB allocation 1304 and second four-PRB allocation 1354) may correspond with an antenna port 42. For some embodiments, DMRS sequence 1390 in subcarrier frequency 3 (of both first four-PRB allocation 1304 and second four-PRB allocation 1354) may correspond with an antenna port 43.

[00121] The correspondence between antenna ports and DMRS sequence 1390 in subcarrier frequencies 0 through 3 (of both first four-PRB allocation 1304 and second four-PRB allocation 1354) may repeat every 4 subcarrier frequencies. In various embodiments, DMRS sequence 1390 in subcarrier frequencies 0 through 47 (of both first four-PRB

allocation 1304 and second four-PRB allocation 1354) may correspond otherwise with various antenna ports.

[00122] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially evenly across the 48 subcarrier frequencies of first four-PRB allocation 1304. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 16 within first four-PRB allocation 1304, and the second subcarrier frequency may be a subcarrier 31 within first four-PRB allocation 1304. For various embodiments, the third subcarrier frequency and fourth subcarrier frequency may be distributed substantially evenly across the 48 subcarrier frequencies of second four-PRB allocation 1354. In some embodiments, the third subcarrier frequency may be a subcarrier frequency 16 within second four-PRB allocation 1354, and the fourth subcarrier frequency may be a subcarrier 31 within second four-PRB allocation 1354. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[00123] In first four-PRB allocation 1304, in some embodiments, the first antenna port, which may correspond with a first set of REs 1311 in odd OFDM symbols of first PCRS sequence 1310, may be an antenna port 44. For some embodiments, the second antenna port, which may correspond with a second set of REs 1312 in even OFDM symbols of first PCRS sequence 1310, may be an antenna port 10 or an antenna port 20 or an antenna port 40. In some embodiments, the third antenna port, which may correspond with a third set of REs 1323 in odd OFDM symbols of second PCRS sequence 1320, may be an antenna port 45. For some embodiments, the fourth antenna port, which may correspond with a fourth set of REs 1324 in even OFDM symbols of second PCRS sequence 1320, may be an antenna port 43. For second four-PRB allocation 1354, in some embodiments, the first antenna port may also correspond with a sixth set of REs 1336 in even OFDM symbols of third PCRS sequence 1330. For some embodiments, the second antenna port may also correspond with a fifth set of REs 1335 in odd OFDM symbols of third PCRS sequence 1330. In some embodiments, the third antenna port may also correspond with an eighth set of REs 1348 in even OFDM symbols of fourth PCRS sequence 1340. For some embodiments, the fourth antenna port may also correspond with a seventh set of REs 1347 in odd OFDM symbols of fourth PCRS sequence 1340. In various embodiments, the first antenna port, the second antenna port, the third antenna port, and/or the fourth antenna port may be other antenna ports.

[00124] Accordingly, second set of REs 1312 (of first PCRS sequence 1310) may correspond with the same antenna port as DMRS sequence 1390 at the first subcarrier frequency, fourth set of REs 1324 (of the second PCRS sequence 1320) may correspond with

the same antenna port as DMRS sequence 1390 at the second subcarrier frequency, fifth set of REs 1335 (of third PCRS sequence 1330) may correspond with the same antenna port as DMRS sequence 1390 at the third subcarrier frequency, and seventh set of REs 1347 (of the fourth PCRS sequence 1340) may correspond with the same antenna port as DMRS sequence 1390 at the fourth subcarrier frequency. In some embodiments, first PCRS sequence 1310, second PCRS sequence 1320, third PCRS sequence 1330, and fourth PCRS sequence 1340 may reuse one or more DMRS signals at those subcarrier frequencies. One or more PCRS signals may accordingly be generated in a manner linked with one or more respectively corresponding DMRS signals at the same subcarrier frequencies.

[00125] In some embodiments, in the first subcarrier frequency in first four-PRB allocation 1304, a first UE may use odd symbols for PCRS (e.g., symbols 3, 5, 7, 9, 11, and/or 13) and a second UE may use even symbols for PCRS (e.g., symbols 4, 6, 8, 10, and/or 12). For some embodiments, in the second subcarrier frequency in first four-PRB allocation 1304, a third UE may use odd symbols for PCRS and a fourth UE may use even symbols for PCRS.

[00126] For some embodiments, in the third subcarrier frequency in second four-PRB allocation 1354, the first UE may use even symbols for PCRS and the second UE may use odd symbols for PCRS. In some embodiments, in the fourth subcarrier frequency in second four-PRB allocation 1354, the third UE may use even symbols for PCRS and the fourth UE may use odd symbols for PCRS.

[00127] An advantage of embodiments such as those depicted in Figs. 13A-13B may be that there may be a PCRS RE for each UE in a given symbol position (which may encompass cases in which there are more than 8 allocated PRBs).

[00128] **Fig. 14** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 1400 may comprise four PRBs 1401 spanning a four-PRB allocation 1404. Pattern 1400 may conform to configuration 5 of subframe configurations 110.

[00129] Pattern 1400 may comprise a first PCRS sequence 1410 carrying PCRS and a second PCRS sequence 1420 carrying PCRS. First PCRS sequence 1410 may be carried at a first subcarrier frequency within four-PRB allocation 1404, and may correspond with a first antenna port and a second antenna port multiplexed in a TDM manner. Second PCRS sequence 1420 may be carried at a second subcarrier frequency within four-PRB allocation 1404, and may correspond with a third antenna port and a fourth antenna port multiplexed in a TDM manner. In various embodiments, pattern 1400 may be substantially similar to

pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 1400 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[00130] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially evenly across the 48 subcarrier frequencies of four-PRB allocation 1404. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 16 within four-PRB allocation 1404, and the second subcarrier frequency may be a subcarrier 31 within four-PRB allocation 1404. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[00131] In some embodiments, the first antenna port, which may correspond with a first set of REs 1411 in odd OFDM symbols of first PCRS sequence 1410, may be an antenna port 50. The second antenna port, which may correspond with a second set of REs 1412 in even OFDM symbols of first PCRS sequence 1410, may be an antenna port 52. For some embodiments, the third antenna port, which may correspond with a third set of REs 1423 in odd OFDM symbols of second PCRS sequence 1420, may be an antenna port 51. The fourth antenna port, which may correspond with a fourth set of REs 1424 in even OFDM symbols of second PCRS sequence 1420, may be an antenna port 53. In various embodiments, the first antenna port, the second antenna port, the third antenna port, and/or the fourth antenna port may be other antenna ports.

[00132] **Fig. 15** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 1500 may comprise four PRBs 1501 spanning a four-PRB allocation 1504. Pattern 1500 may conform to configuration 5 of subframe configurations 110.

[00133] Pattern 1500 may comprise a first PCRS sequence 1510 carrying PCRS and a second PCRS sequence 1520 carrying PCRS. First PCRS sequence 1510 may be carried at a first subcarrier frequency within four-PRB allocation 1504, and may correspond with a first antenna port and a second antenna port multiplexed in a TDM manner. Second PCRS sequence 1520 may be carried at a second subcarrier frequency within four-PRB allocation 1504, and may correspond with a third antenna port and a fourth antenna port multiplexed in a TDM manner. In various embodiments, pattern 1500 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 1500 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[00134] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially evenly across the 48 subcarrier frequencies of four-PRB allocation 1504. In some embodiments, the first subcarrier

frequency may be a subcarrier frequency 16 within four-PRB allocation 1504, and the second subcarrier frequency may be a subcarrier 31 within four-PRB allocation 1504. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[00135] In some embodiments, the first antenna port, which may correspond with a first set of REs 1511 in odd OFDM symbols of first PCRS sequence 1510, may be an antenna port 52. The second antenna port, which may correspond with a second set of REs 1512 in even OFDM symbols of first PCRS sequence 1510, may be an antenna port 50. For some embodiments, the third antenna port, which may correspond with a third set of REs 1523 in odd OFDM symbols of second PCRS sequence 1520, may be an antenna port 53. The fourth antenna port, which may correspond with a fourth set of REs 1524 in even OFDM symbols of second PCRS sequence 1520, may be an antenna port 51. In various embodiments, the first antenna port, the second antenna port, the third antenna port, and/or the fourth antenna port may be other antenna ports.

[00136] With respect to **Figs. 14 and 15**, in various embodiments, UL PCRS may be associated with xPUSCH transmissions. In some embodiments, UL PCRS may be transmitted on an antenna port assigned to a UE, such as antenna ports $p \in \{50, 51, 52, 53\}$. For some embodiments, UL PCRS may be present and may be a valid reference for phase noise compensation, such as if an xPUSCH transmission is associated with the corresponding antenna port. In some embodiments, UL PCRS may be transmitted on PRBs and symbols (e.g., in REs) upon which a corresponding xPUSCH is mapped.

[00137] For antenna ports $p \in \{50, 51, 52, 53\}$, in a PRB having a frequency-domain index n_{PRB} assigned for a corresponding xPUSCH transmission, a DMRS $a_{k,2}^{(p'),DMRS}$ associated with the xPUSCH may be disposed to being mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ for one or more corresponding xPUSCH symbols in a subframe (up to and including all xPUSCH symbols) according to the following equation:

$$a_{k,l}^{(p)} = a_{k,2}^{(p'),DMRS}$$

In the equation, p' may be a DMRS port number associated with the xPUSCH transmission.

[00138] A starting resource block number of an xPUSCH physical resource allocation n_{PRB}^{xPUSCH} in the frequency domain, a resource allocation bandwidth in terms of a number of resource blocks N_{PRB}^{xPUSCH} , and resource elements (k, l) in a subframe may be given by the following equations:

$$\begin{aligned}
k &= N_{sc}^{RB} \cdot (n_{PRB}^{xPUSCH} + \lfloor m'/4 \rfloor \cdot 4) + k' \\
k' &= \begin{cases} 16 & p \in \{50, 51\} \\ 31 & p \in \{52, 53\} \end{cases} \\
l' &= \begin{cases} \begin{cases} 3, 5, 7, 9, 11 & p \in \{50 + m'', 52 + m''\} \\ 4, 6, 8, 10 & p \in \{51 - m'', 53 - m''\} \end{cases} & \text{if Subframe configuration} = 7 \text{ or } 8 \\ \begin{cases} 3, 5, 7, 9, 11 & p \in \{50 + m'', 52 + m''\} \\ 4, 6, 8, 10, 12 & p \in \{51 - m'', 53 - m''\} \end{cases} & \text{if Subframe configuration} = 5 \text{ or } 6 \\ \begin{cases} 3, 5, 7, 9, 11, 13 & p \in \{50 + m'', 52 + m''\} \\ 4, 6, 8, 10, 12 & p \in \{51 - m'', 53 - m''\} \end{cases} & \text{if Subframe configuration} = 4 \end{cases} \\
m' &= 0, 1, 2, \dots, N_{PRB}^{xPUSCH} - 1 \\
m'' &= \lfloor m'/4 \rfloor \% 2
\end{aligned}$$

In the equations, k may be an index corresponding with subcarrier position (e.g., a subcarrier frequency or a subcarrier frequency index), l' may be a symbol index within a subframe, and m' may be a PRB index.

[00139] Resource elements (k, l) may be used for transmission of UE-specific PCRS from one UE on an antenna port in a set S , where $S = \{50\}$, $S = \{51\}$, $S = \{52\}$, and $S = \{53\}$ might not be used for transmission of xPUSCH on any antenna port in the same subframe.

[00140] **Fig. 16** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 1600 may comprise four PRBs 1601 spanning a four-PRB allocation 1604. Pattern 1600 may comprise a first PCRS sequence 1610 carrying PCRS and a second PCRS sequence 1620 carrying PCRS. First PCRS sequence 1610 may be carried at a first subcarrier frequency within four-PRB allocation 1604, and may correspond with a first antenna port and a second antenna port multiplexed in a TDM manner. Second PCRS sequence 1620 may be carried at a second subcarrier frequency within four-PRB allocation 1604, and may correspond with a third antenna port and a fourth antenna port multiplexed in a TDM manner. In various embodiments, pattern 1600 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 1600 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[00141] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially evenly across the 48 subcarrier frequencies of four-PRB allocation 1604. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 16 within four-PRB allocation 1604, and the second

subcarrier frequency may be a subcarrier 31 within four-PRB allocation 1604. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[00142] In some embodiments, the first antenna port, which may correspond with a first set of REs 1611 in odd OFDM symbols of first PCRS sequence 1610, may be an antenna port 40. The second antenna port, which may correspond with a second set of REs 1612 in even OFDM symbols of first PCRS sequence 1610, may be an antenna port 42. For some embodiments, the third antenna port, which may correspond with a third set of REs 1623 in odd OFDM symbols of second PCRS sequence 1620, may be an antenna port 41. The fourth antenna port, which may correspond with a fourth set of REs 1624 in even OFDM symbols of second PCRS sequence 1620, may be an antenna port 43. In various embodiments, the first antenna port, the second antenna port, the third antenna port, and/or the fourth antenna port may be other antenna ports.

[00143] In some embodiments, there may be a plurality of PCRS antenna ports available (e.g., four PCRS antenna ports), two of which may be multiplexed by TDM. In such embodiments, those four PCRS antenna ports may be of limited use if four MU-MIMO is scheduled in uplink. Many transmissions may be single rank, Space Frequency Block Coding (SFBC), and rank-2/rank-4 transmissions in a UE with SU-MIMO that is disposed to using a single UL PCRS antenna port. With two MU-MIMO, merely two antenna ports may be needed, and TDM might not be employed. Non-TDM may advantageously provide a doubled reference signal to a receiver for compensating phase noise, and thus it could be beneficial for higher Modulation and Coding Scheme (MCS) transmissions.

[00144] In one embodiment, in a case of TDM in UL PCRS, UL DCI may include a 1-bit indication to configure a corresponding UE to transmit PCRS using two PCRS antenna ports, which may be TDM in a given RE position. (An RE position may comprise a subcarrier frequency and/or one or more OFDM symbols at which one or more REs are carried.) UL DCI may accordingly include the 1-bit indication to configure a corresponding UE to transmit PCRS in a non-TDM manner for a given RE position.

[00145] For example, with reference to **Fig. 16**, there may be four PCRS antenna ports. With the 1-bit indication having a first value (e.g., a value of 0), a corresponding UE may merely transmit a PCRS sequence in a single PCRS antenna port (which may be signaled, or may be implicitly determined, e.g., from an xPUSCH DMRS antenna port). With the 1-bit indication having a second value (e.g., a value of 1), the corresponding UE may use two PCRS antenna ports for UL PCRS transmissions (e.g., both antenna port 40 and antenna port 42, if a signaled or implicitly determined DMRS antenna ports is antenna port 40 or antenna

port 42). An eNB may then receive both antenna ports (e.g., antenna port 40 and antenna port 42) together from the UE, and may utilize both for compensating a phase noise.

[00146] For some embodiments, when DMRS utilizes two antenna ports located in different RE positions, an indication bit may be set to have a first value (e.g., a value of 0) or a second value (e.g., a value of 1), and two PCRS ports in the RE where a primary DMRS antenna port is located (in the transmission mode of multiple DMRS ports) may be utilized. In some embodiments, the primary DMRS antenna port may be defined as one that has a lowest DMRS antenna port number. For some embodiments, the primary DMRS antenna port may be defined as one that has a highest DMRS antenna port number.

[00147] For example, an xPUSCH transmission may have two DMRS antenna ports linked to PCRS antenna ports (such as antenna port 40 and antenna port 41). In some embodiments, a primary DMRS antenna port may be assumed to be one linked to a PCRS antenna port based on a lowest port-number selection rule. In such embodiments, a value of 1 for the proposed indication bit may indicate that the primary DMRS antenna port may be linked to PCRS antenna port 40, and that a UE may transmit PCRSs on both PCRS antenna port 40 and PCRS antenna port 42. PCRS antenna port 40 may be the primary antenna port, and PCRS antenna port 42 may be a secondary antenna port.

[00148] For some embodiments, a primary DMRS antenna port may be assumed to be one linked to a PCRS antenna port based on a highest port-number selection rule. In such embodiments, a value of 1 for the proposed indication bit may indicate that the primary DMRS antenna port may be linked to PCRS antenna port 41, and that a UE may transmit PCRSs on both PCRS antenna port 41 and PCRS antenna port 43. PCRS antenna port 41 may be the primary antenna port, and PCRS antenna port 43 may be a secondary antenna port.

[00149] From a UE point of view, a variety of procedures and/or proposed operations may be provided. In a first procedure, a UE may detect an xPDCCH with a DCI format A1 in a subframe n intended for the UE, where a dual-PCRS field in the DCI may be set to 0. The UE may then be disposed to transmitting a UL PCRS sequence in a subframe $n+k$ using a primary PCRS antenna port, where the primary PCRS antenna port may be an antenna port having a lowest antenna port number among associated PCRS antenna ports in the DCI.

[00150] In a second procedure, a UE may detect an xPDCCH with a DCI format A1 in a subframe n intended for the UE, where a dual-PCRS field in the DCI may be set to 1. The UE may then be disposed to transmitting a UL PCRS sequence in a subframe $n+k$ using a

primary PCRS antenna port and a secondary PCRS antenna port, where the secondary PCRS antenna port may share an RE position with the primary PCRS antenna port.

[00151] In a third procedure, a UE may detect an xPDCCH with a DCI format A2 in a subframe n intended for the UE, where a dual-PCRS field in the DCI may be set to 0. The UE may then be disposed to transmitting a UL PCRS sequence in a subframe $n+k$ using a primary PCRS antenna port, where the primary PCRS antenna port may be an antenna port having a lowest antenna port number among associated PCRS antenna ports in the DCI.

[00152] In a fourth procedure, a UE may detect an xPDCCH with a DCI format A2 in a subframe n intended for the UE, where a dual-PCRS field in the DCI may be set to 1. The UE may then be disposed to transmitting a UL PCRS sequence in a subframe $n+k$ using a primary PCRS antenna port and a secondary PCRS antenna port, where the secondary PCRS antenna port may share an RE position with the primary PCRS antenna port.

[00153] For various procedures, a UE may identify UL PCRS antenna ports from one or more corresponding xPUSCH DMRS antenna ports. For example, UL PCRS antenna ports and/or xPUSCH DMRS antenna ports may be one or more of antenna port 40, antenna port 41, antenna port 42, and/or antenna port 43.

[00154] In various embodiments, a number of antenna ports for PCRS may differ from a number of antenna ports for DMRS. Some embodiments may not incorporate implicit mapping between PCRS antenna ports and DMRS antenna ports. For example, a UE may have multiple DMRS antenna ports, and those DMRS ports may be multiplexed in a code domain, e.g. by using an OCC (Orthogonal Cover Code). Then, for a given RE and/or subcarrier frequency index, the UE may have multiple signals for the various antenna ports. For example, in some embodiments, antenna port may be multiplied by +1 (OCC), and the other antenna port may be multiplexed by -1 (OCC).

[00155] In a first set of embodiments for relating PCRS antenna port numbers and DMRS antenna port numbers, PCRS antenna ports may correspond to one or more dedicated sequence sets. For the first set of embodiments, a PCRS antenna port and/or a set of PCRS antenna ports may be explicitly indicated in DCI, or in higher-layer signaling. The PCRS sequence may be determined by PCRS antenna port number. The RE positions (or RE symbols positions, in TDM cases) may be fixed according to PCRS antenna port numbers.

[00156] For example, in some embodiments, DL PCRS REs may be carried in subcarrier frequency 23 and subcarrier frequency 24 every four PRBs for PCRS antenna port 61 and PCRS antenna port 60, respectively. The assigned REs indicated by PCRS antenna port numbers, or by relevant signaling, may be used every four PRBs among allocated

xPDSCH PRBs, regardless of DMRS antenna port usage. Every four PRBs, there may be a deterministic PCRS sequence set per PCRS antenna port.

[00157] **Fig. 17** illustrates an example pattern of DL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 1700 may comprise four PRBs 1701 spanning a four-PRB allocation 1704. Pattern 1700 may comprise a first PCRS sequence 1710 carrying PCRS and a second PCRS sequence 1720 carrying PCRS. First PCRS sequence 1710 may be carried at a first subcarrier frequency within four-PRB allocation 1704, and may correspond with a first antenna port. Second PCRS sequence 1720 may be carried at a second subcarrier frequency within four-PRB allocation 1704, and may correspond with a second antenna port. In various embodiments, pattern 1700 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 1700 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[00158] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially about a center of the 48 subcarrier frequencies of four-PRB allocation 1704, which may advantageously address a potentially higher Inter-Carrier Interference (ICI) that may exist at a center of four-PRB allocation 1704. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 23 within four-PRB allocation 1704, and the second subcarrier frequency may be a subcarrier 24 within four-PRB allocation 1704. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[00159] In some embodiments, the first antenna port may be antenna port 61, and the second antenna port may be an antenna port 60. In various embodiments, the first antenna port and/or the second antenna port may be other antenna ports.

[00160] For some embodiments, DL PCRS may be associated with xPDSCH, and may be transmitted on one or more antenna ports signaled in DCI (e.g., an antenna port and/or an antenna port $p = 61$). Table 1 provides signaling that may be added in DL DCI to indicate the one or more antenna ports for transmitting DL PCRS.

Table 1: additional DL DCI Signaling

Signalling Bits	Configurations	Note
00	No PCRS is transmitted	Both PCRS REs are used for xPDSCH
01	PCRS is transmitted in antenna port 60	Both PCRS REs are not used for xPDSCH
10	PCRS is transmitted in antenna port 61	
11	PCRS is transmitted in both antenna ports 60 and 61	

For some embodiments, DL PCRS may be present and may be a valid reference for phase noise compensation, such as if an xPDSCH transmission is associated with the corresponding antenna port. In some embodiments, DL PCRS may be transmitted on PRBs and symbols (e.g., in REs) upon which a corresponding xPDSCH is mapped. For some embodiments, DL PCRS may be identical in a plurality of symbols (up to and including all symbols) corresponding to an xPDSCH allocation.

[00161] In some embodiments, for one or more antenna ports $p \in \{60, 61\}$, a reference-signal sequence $r(m)$ may be defined by the following equations:

$$r(m) = \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m+1)), \quad m = 0, 1, \dots, \lfloor N_{RB}^{\max, DL} / 4 \rfloor - 1$$

[00162] For some embodiments, a pseudo-random sequence generator may be initialized at the start of each subframe as follows:

$$c_{\text{init}} = (\lfloor n_s / 2 \rfloor + 1) \cdot (2n_{\text{ID}}^{(n_{\text{SCID}})} + 1) \cdot 2^{16} + n_{\text{SCID}}$$

The quantities $n_{\text{ID}}^{(i)}$, $i = 0, 1$ may be given by $n_{\text{ID}}^{(i)} = N_{\text{ID}}^{\text{cell}}$ if no value for $n_{\text{ID}}^{\text{DMRS}, i}$ is provided by higher layers, and otherwise may be given by $n_{\text{ID}}^{(i)} = n_{\text{ID}}^{\text{DMRS}, i}$. The value of n_{SCID} may be zero unless specified otherwise. For an xPDSCH transmission, n_{SCID} may be given by a DCI format associated with the xPDSCH transmission.

[00163] In some embodiments, for antenna ports $p \in \{60, 61\}$, in a physical resource block with frequency-domain index n_{PRB} assigned for a corresponding xPDSCH transmission, a part of a reference signal sequence $r(m)$ may be disposed to being mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ for all xPDSCH symbols in a subframe, as follows:

$$a_{k,l}^{(p)} = r(k'')$$

[00164] A starting resource block number of xPDSCH physical resource allocation n_{PRB}^{xPDSCH} in the frequency domain, a resource allocation bandwidth in terms of number of resource blocks N_{PRB}^{xPDSCH} , and resource elements (k, l) in a subframe may be given by the following equations:

$$\begin{aligned} k &= N_{sc}^{RB} \cdot (n_{PRB}^{xPDSCH} + k'' \cdot 4) + k' \\ k' &= \begin{cases} 24 & p \in 60 \\ 23 & p \in 61 \end{cases} \\ k'' &= \lfloor m' / 4 \rfloor \\ l' &= l_{first}^{xPDSCH}, \dots, l_{last}^{xPDSCH} \\ m' &= 0, 1, 2, \dots, N_{PRB}^{xPDSCH} - 1 \end{aligned}$$

In the equations, k may be an index corresponding with subcarrier position (e.g., a subcarrier frequency or a subcarrier frequency index), l' may be a symbol index within a subframe, m' may be a PRB index, and l_{first}^{xPDSCH} and l_{last}^{xPDSCH} may be symbol indices of a first and a last of xPDSCH, respectively, for the given subframe.

[00165] Resource elements (k, l) may be used for transmission of UE-specific PCRS on any of the antenna ports in a set S , where $S = \{60\}$ and $S = \{61\}$, might not be used for transmission of xPDSCH on any antenna port in the same subframe.

[00166] For some embodiments, four-PRB allocation 1604 may comprise REs used for PCRS for antenna port 60 and antenna port 61 when xPDSCH is transmitted from

$$l_{first}^{xPDSCH} = 3 \text{ to } l_{last}^{xPDSCH} = 13.$$

[00167] In another example, UL PCRS REs may be carried in subcarrier frequency 16 and subcarrier frequency 31 every four PRBs, respectively, for a first PCRS antenna port set comprising PCRS antenna port 40 and 41, and for a second PCRS antenna port set comprising PCRS antenna port 42 and 43. Every four PRBs, there may be deterministic PCRS sequence set per PCRS antenna port.

[00168] **Fig. 18** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 1800 may comprise four PRBs 1801 spanning a four-PRB allocation 1804. Pattern 1800 may comprise a first PCRS sequence 1810 carrying PCRS and a second PCRS sequence 1820 carrying PCRS. First PCRS sequence 1810 may be carried at a first subcarrier frequency within four-PRB allocation 1804, and may correspond with a first antenna port and a second antenna port multiplexed in a TDM manner. Second PCRS sequence 1820 may be carried at

a second subcarrier frequency within four-PRB allocation 1804, and may correspond with a third antenna port and a fourth antenna port multiplexed in a TDM manner. In various embodiments, pattern 1800 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 1800 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[00169] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially evenly across the 48 subcarrier frequencies of four-PRB allocation 1804. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 16 within four-PRB allocation 1804, and the second subcarrier frequency may be a subcarrier 31 within four-PRB allocation 1804. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[00170] In some embodiments, the first antenna port, which may correspond with a first set of REs 1811 in odd OFDM symbols of first PCRS sequence 1810, may be an antenna port 40. The second antenna port, which may correspond with a second set of REs 1812 in even OFDM symbols of first PCRS sequence 1810, may be an antenna port 42. For some embodiments, the third antenna port, which may correspond with a third set of REs 1823 in odd OFDM symbols of second PCRS sequence 1820, may be an antenna port 41. The fourth antenna port, which may correspond with a fourth set of REs 1824 in even OFDM symbols of second PCRS sequence 1820, may be an antenna port 43. In various embodiments, the first antenna port, the second antenna port, the third antenna port, and/or the fourth antenna port may be other antenna ports.

[00171] **Fig. 19** illustrates an example pattern of UL PCRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 1900 may comprise four PRBs 1901 spanning a four-PRB allocation 1904. Pattern 1900 may comprise a first PCRS sequence 1910 carrying PCRS and a second PCRS sequence 1920 carrying PCRS. First PCRS sequence 1910 may be carried at a first subcarrier frequency within four-PRB allocation 1904, and may correspond with a first antenna port and a second antenna port multiplexed in a TDM manner. Second PCRS sequence 1920 may be carried at a second subcarrier frequency within four-PRB allocation 1904, and may correspond with a third antenna port and a fourth antenna port multiplexed in a TDM manner. In various embodiments, pattern 1900 may be substantially similar to pattern 200 (and/or other patterns disclosed herein), and the elements of pattern 1900 may be substantially similar to the elements of pattern 200 (and/or other patterns disclosed herein).

[00172] In various embodiments, the first subcarrier frequency and the second subcarrier frequency may be distributed substantially evenly across the 48 subcarrier frequencies of four-PRB allocation 1904. In some embodiments, the first subcarrier frequency may be a subcarrier frequency 16 within four-PRB allocation 1904, and the second subcarrier frequency may be a subcarrier 31 within four-PRB allocation 1904. For various embodiments, the subcarrier frequencies may be other subcarrier frequencies.

[00173] In some embodiments, the first antenna port, which may correspond with a first set of REs 1911 in odd OFDM symbols of first PCRS sequence 1910, may be an antenna port 42. The second antenna port, which may correspond with a second set of REs 1912 in even OFDM symbols of first PCRS sequence 1910, may be an antenna port 40. For some embodiments, the third antenna port, which may correspond with a third set of REs 1923 in odd OFDM symbols of second PCRS sequence 1920, may be an antenna port 43. The fourth antenna port, which may correspond with a fourth set of REs 1924 in even OFDM symbols of second PCRS sequence 1920, may be an antenna port 41. In various embodiments, the first antenna port, the second antenna port, the third antenna port, and/or the fourth antenna port may be other antenna ports.

[00174] With respect to **Figs. 18 and 19**, in various embodiments, UL PCRS may be associated with xPUSCH transmissions. In some embodiments, UL PCRS may be transmitted on an antenna port assigned to a UE, such as antenna ports $p \in \{40, 41, 42, 43\}$. For some embodiments, UL PCRS may be present and may be a valid reference for phase noise compensation, such as if an xPUSCH transmission is associated with the corresponding antenna port. In some embodiments, UL PCRS may be transmitted on PRBs and symbols (e.g., in REs) upon which a corresponding xPUSCH is mapped.

[00175] In some embodiments, for one or more of antenna ports $p \in \{40, 41, 42, 43\}$, a reference-signal sequence $r(m)$ may be defined by the following equations:

$$r(m) = \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m+1)), \quad m = 0, 1, \dots, \lfloor N_{RB}^{\max, UL} / 4 \rfloor - 1$$

[00176] For some embodiments, a pseudo-random sequence generator may be initialized with at the start of each subframe as follows:

$$c_{\text{init}} = (\lfloor n_s / 2 \rfloor + 1) \cdot (2^{n_{\text{ID}}^{\text{SCID}}} + 1) \cdot 2^{16} + n_{\text{SCID}}$$

The quantities $n_{\text{ID}}^{(i)}$, $i = 0, 1$ may be given by $n_{\text{ID}}^{(i)} = N_{\text{ID}}^{\text{cell}}$ if no value for $n_{\text{ID}}^{\text{DMRS}, i}$ is provided by higher layers, and otherwise may be given by $n_{\text{ID}}^{(i)} = n_{\text{ID}}^{\text{DMRS}, i}$. The value of n_{SCID} may be zero

unless specified otherwise. For an xPUSCH transmission, n_{SCID} may be given by a DCI format associated with the xPUSCH transmission.

[00177] In some embodiments, for antenna ports $p \in \{40, 41, 42, 43\}$, in a physical resource block with frequency-domain index n_{PRB} assigned for a corresponding xPUSCH transmission, a part of a reference signal sequence $r(m)$ may be disposed to being mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ for all xPUSCH symbols in a subframe, as follows:

$$a_{k,l}^{(p)} = r(k'')$$

[00178] A starting physical resource block index of xPUSCH physical resource allocation $n_{\text{PRB}}^{\text{xPUSCH}}$, a total number of allocated xPUSCH physical resource blocks $N_{\text{PRB}}^{\text{xPUSCH}}$, and resource elements (k, l) in a subframe may be given by the following equations:

$$\begin{aligned} k &= N_{\text{sc}}^{\text{RB}} \cdot (n_{\text{PRB}}^{\text{xPUSCH}} + k' \cdot 4) + k' \\ k' &= \begin{cases} 16 & p \in \{40, 42\} \\ 31 & p \in \{41, 43\} \end{cases} \\ k'' &= \lfloor m' / 4 \rfloor \\ l' &= \begin{cases} \{l' \mid l' \in \{3, \dots, l_{\text{last}}^{\text{xPUSCH}}\} \text{ and } l' \text{ is an odd number}\}, & p \in \{40 + 2 \cdot m'', 41 + 2 \cdot m''\} \\ \{l' \mid l' \in \{3, \dots, l_{\text{last}}^{\text{xPUSCH}}\} \text{ and } l' \text{ is an even number}\}, & p \in \{42 - 2 \cdot m'', 43 - 2 \cdot m''\} \end{cases} \\ m' &= 0, 1, 2, \dots, N_{\text{PRB}}^{\text{xPUSCH}} - 1 \\ m'' &= \lfloor m' / 4 \rfloor \% 2 \end{aligned}$$

In the equations, $m' = 0, 1, 2, \dots, N_{\text{PRB}}^{\text{xPUSCH}} - 1$ may be a PRB index, l' may be a symbol index within a subframe, and $l_{\text{last}}^{\text{xPUSCH}}$ may be a symbol index of an end of xPUSCH, for the given subframe. For example, for pattern 1800 of **Fig. 18**, m'' may be 0, and for pattern 1900 of **Fig. 19**, m'' may be 1.

[00179] Resource elements (k, l) used for transmission of UE-specific PCRS on any of the antenna ports in the set S , where $S = \{40\}$, $S = \{41\}$, $S = \{42\}$, and $S = \{43\}$, might not be used for transmission of xPUSCH on any antenna port in the same subframe.

[00180] For some embodiments, four-PRB allocation 1804 and/or four-PRB allocation 1904 may comprise REs used for PCRS for antenna port 40, antenna port 41, antenna port 42, and/or antenna port 43, when $l_{\text{last}}^{\text{xPUSCH}} = 12$.

[00181] In a second set of embodiments for relating PCRS antenna port numbers and DMRS antenna port numbers, DMRS antenna ports and PCRS antenna ports may have an implicit relationship. Some embodiments may use a sequence of lowest DMRS antenna ports

in a subframe, or a sequence of highest DMRS antenna ports in a subframe. The sequence may be applied even if there is no DMRS signal in the same PCRS RE positions for a transmit-side to send. Some embodiments may use a sequence of lowest DMRS antenna ports in a PCRS RE position. The sequence may use one or more DMRS symbols as one or more additional PCRS symbols.

[00182] Among multiple DMRS antenna ports, some DMRS antenna ports may be used for certain transmissions. For PCRS antenna ports having fixed positions, and for DMRS having Frequency-Division Multiplexing (FDM) with multiple DMRS ports, there may be cases in which no DMRS exists for some PCRS RE positions. Therefore, various rules may advantageously specify PCRS sequences that may be transmitted in such cases.

[00183] For DL transmission, DL PCRS may be a cell-specific signal. All MU-MIMO users may receive a DL PCRS antenna port for PCRS. A PCRS sequence for a PCRS antenna port may be varied, depending upon MU-MIMO multiplexing, or ranks in SU-MIMO transmission. For a given PCRS antenna port, a DMRS sequence may be selected among multiple DMRS antenna ports.

[00184] For example, a DMRS port selection per TB may be determined based on various criteria. For SU-MIMO instances, a lowest DMRS port number or a highest DMRS port number may be used for the reference, on a per-TP basis. In a single rank instance, a RS sequence for a single DMRS antenna port may be used for PCRS for a given frequency position. A receiver may determine the PCRS antenna port number by virtue of DMRS antenna port indications. In an SFBC or spatial multiplexing instance, an RS sequence for a lowest DMRS antenna port number (or highest DMRS antenna port number) may be used for PCRS for a given frequency position. For example, an eNB may transmit a rank-2 transmission to a User A using DMRS antenna port 50 and DMRS antenna port 52, then a PCRS port may use a DMRS sequence for port 50 (in accordance with a lowest DMRS antenna port rule).

[00185] For SU-MIMO instances, a lowest DMRS port number or a highest DMRS port number in a PCRS RE position may be used for the reference, on a per-TP basis; and possible DMRS antenna ports may be limited to available DMRS antenna ports in a PCRS RE position. This may advantageously utilize one or more DMRS symbols as one or more additional PCRS symbols.

[00186] For MU-MIMO instances, an eNB may pick an MU-MIMO user, and may use a rule substantially similar to an SU-MIMO rule. DCI may include a reference antenna port number, or relevant information for a PCRS sequence, and may provide those to other MU-

MIMO users. A predetermined DMRS antenna port corresponding to a TP index may be used in MU-MIMO cases.

[00187] In a third set of embodiments for relating PCRS antenna port numbers and DMRS antenna port numbers, different RE positions may be used depending upon DMRS antenna ports. **Fig. 20** illustrates an example pattern of DL DMRS transmission across a four-PRB allocation, in accordance with some embodiments of the disclosure. A pattern 2000 may comprise four PRBs 2001 spanning a four-PRB allocation 2004. Pattern 2000 may also comprise a DMRS sequence 2090 spanning 48 subcarrier frequencies in OFDM symbol 2. In some embodiments, DMRS sequence 2090 in subcarrier frequency 0 may correspond with one of an antenna port 10 or an antenna port 20 or an antenna port 40. For some embodiments, DMRS sequence 2090 in subcarrier frequency 1 may correspond with one of an antenna port 21 or an antenna port 41. In some embodiments, DMRS sequence 2090 in subcarrier frequency 2 may correspond with an antenna port 42. For some embodiments, DMRS sequence 2090 in subcarrier frequency 3 may correspond with an antenna port 43. The correspondence between antenna ports and DMRS sequence 2090 in subcarrier frequencies 0 through 3 may repeat every 4 subcarrier frequencies. In various embodiments, DMRS sequence 2090 in subcarrier frequencies 0 through 47 may correspond otherwise with various antenna ports.

[00188] In some instances, there might be no DMRS signal in a PCRS RE. Different PCRS RE positions may instead depending on a usage of DMRS ports. A position may be determined by an associated DMRS port position, and a PCRS sequence may be selected by one of the associated DMRS sequences based on a lowest DMRS port number rule or a highest DMRS port number rule.

[00189] In some exemplary DMRS antenna port mappings, there may be FDM between one of antenna port 10 or antenna port 20 or antenna port 40, one of antenna port 21 or antenna port 41, antenna port 42, and antenna port 43, and Code Division Multiplexing (CDM) may be used within a set (e.g., between antenna port 10, antenna port 20, and antenna port 40).

[00190] So, in one example, when an eNB transmits a rank-2 transmission using DMRS antenna port 10 and DMRS antenna port 20, an RE position 24 (e.g., a subcarrier frequency 24, which may correspond to antenna port 10 or antenna port 20 or antenna port 40) may be used, and the same sequence with DMRS antenna port 10 (in accordance with a lowest antenna port rule) may be used for PCRS transmission for the TP.

[00191] In another example, when an eNB transmits a rank-2 transmission using DMRS antenna port 21 and DMRS antenna port 41, an RE position 25 (e.g., a subcarrier frequency 25, which may correspond to antenna port 21 or antenna port 41) may be used, and the same sequence with DMRS antenna port 21 (in accordance with a lowest antenna port rule) may be used for PCRS transmission for the TP.

[00192] In a further example, when an eNB transmits a rank-2 transmission using DMRS antenna port 21 and DMRS antenna port 42, an RE position 25 (e.g., a subcarrier frequency 25) may be used (in accordance with a lowest antenna port rule), or an RE position 26 (e.g., a subcarrier frequency 26) may be used (in accordance with a highest antenna port rule), may be used for PCRS transmission for the TP.

[00193] **Fig. 21** illustrates an eNB and a UE, in accordance with some embodiments of the disclosure. **Fig. 21** includes block diagrams of an eNB 2110 and a UE 2130 which are operable to co-exist with each other and other elements of an LTE network. High-level, simplified architectures of eNB 2110 and UE 2130 are described so as not to obscure the embodiments. It should be noted that in some embodiments, eNB 2110 may be a stationary non-mobile device.

[00194] eNB 2110 is coupled to one or more antennas 2105, and UE 2130 is similarly coupled to one or more antennas 2125. However, in some embodiments, eNB 2110 may incorporate or comprise antennas 2105, and UE 2130 in various embodiments may incorporate or comprise antennas 2125.

[00195] In some embodiments, antennas 2105 and/or antennas 2125 may comprise one or more directional or omni-directional antennas, including monopole antennas, dipole antennas, loop antennas, patch antennas, microstrip antennas, coplanar wave antennas, or other types of antennas suitable for transmission of RF signals. In some MIMO (multiple-input and multiple output) embodiments, antennas 2105 are separated to take advantage of spatial diversity.

[00196] eNB 2110 and UE 2130 are operable to communicate with each other on a network, such as a wireless network. eNB 2110 and UE 2130 may be in communication with each other over a wireless communication channel 2150, which has both a downlink path from eNB 2110 to UE 2130 and an uplink path from UE 2130 to eNB 2110.

[00197] As illustrated in **Fig. 21**, in some embodiments, eNB 2110 may include a physical layer circuitry 2112, a MAC (media access control) circuitry 2114, a processor 2116, a memory 2118, and a hardware processing circuitry 2120. A person skilled in the art will

appreciate that other components not shown may be used in addition to the components shown to form a complete eNB.

[00198] In some embodiments, physical layer circuitry 2112 includes a transceiver 2113 for providing signals to and from UE 2130. Transceiver 2113 provides signals to and from UEs or other devices using one or more antennas 2105. In some embodiments, MAC circuitry 2114 controls access to the wireless medium. Memory 2118 may be, or may include, a storage media/medium such as a magnetic storage media (e.g., magnetic tapes or magnetic disks), an optical storage media (e.g., optical discs), an electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any tangible storage media or non-transitory storage media. Hardware processing circuitry 2120 may comprise logic devices or circuitry to perform various operations. In some embodiments, processor 2116 and memory 2118 are arranged to perform the operations of hardware processing circuitry 2120, such as operations described herein with reference to logic devices and circuitry within eNB 2110 and/or hardware processing circuitry 2120.

[00199] Accordingly, in some embodiments, eNB 2110 may be a device comprising an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device.

[00200] As is also illustrated in **Fig. 21**, in some embodiments, UE 2130 may include a physical layer circuitry 2132, a MAC circuitry 2134, a processor 2136, a memory 2138, a hardware processing circuitry 2140, a wireless interface 2142, and a display 2144. A person skilled in the art would appreciate that other components not shown may be used in addition to the components shown to form a complete UE.

[00201] In some embodiments, physical layer circuitry 2132 includes a transceiver 2133 for providing signals to and from eNB 2110 (as well as other eNBs). Transceiver 2133 provides signals to and from eNBs or other devices using one or more antennas 2125. In some embodiments, MAC circuitry 2134 controls access to the wireless medium. Memory 2138 may be, or may include, a storage media/medium such as a magnetic storage media (e.g., magnetic tapes or magnetic disks), an optical storage media (e.g., optical discs), an electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any tangible storage media or non-transitory storage media. Wireless interface 2142 may be arranged to allow the processor to communicate with another device. Display 2144 may provide a visual and/or tactile display for a user to interact with UE 2130, such as a touch-screen display. Hardware processing circuitry 2140 may comprise logic devices or circuitry to perform various operations. In some embodiments, processor

2136 and memory 2138 may be arranged to perform the operations of hardware processing circuitry 2140, such as operations described herein with reference to logic devices and circuitry within UE 2130 and/or hardware processing circuitry 2140.

[00202] Accordingly, in some embodiments, UE 2130 may be a device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display.

[00203] Elements of **Fig. 21**, and elements of other figures having the same names or reference numbers, can operate or function in the manner described herein with respect to any such figures (although the operation and function of such elements is not limited to such descriptions). For example, **Figs. 22-23 and 30** also depict embodiments of eNBs, hardware processing circuitry of eNBs, UEs, and/or hardware processing circuitry of UEs, and the embodiments described with respect to **Fig. 21** and **Figs. 22-23 and 30** can operate or function in the manner described herein with respect to any of the figures.

[00204] In addition, although eNB 2110 and UE 2130 are each described as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements and/or other hardware elements. In some embodiments of this disclosure, the functional elements can refer to one or more processes operating on one or more processing elements. Examples of software and/or hardware configured elements include Digital Signal Processors (DSPs), one or more microprocessors, DSPs, Field-Programmable Gate Arrays (FPGAs), Application Specific Integrated Circuits (ASICs), Radio-Frequency Integrated Circuits (RFICs), and so on.

[00205] **Fig. 22** illustrates hardware processing circuitries for an eNB for PCRS, in accordance with some embodiments of the disclosure. With reference to **Fig. 21**, an eNB may include various hardware processing circuitries discussed herein (such as hardware processing circuitry 2200 of **Fig. 22**), which may in turn comprise logic devices and/or circuitry operable to perform various operations. For example, in **Fig. 21**, eNB 2110 (or various elements or components therein, such as hardware processing circuitry 2120, or combinations of elements or components therein) may include part of, or all of, these hardware processing circuitries.

[00206] In some embodiments, one or more devices or circuitries within these hardware processing circuitries may be implemented by combinations of software-configured elements and/or other hardware elements. For example, processor 2116 (and/or one or more other processors which eNB 2110 may comprise), memory 2118, and/or other elements or

components of eNB 2110 (which may include hardware processing circuitry 2120) may be arranged to perform the operations of these hardware processing circuitries, such as operations described herein with reference to devices and circuitry within these hardware processing circuitries. In some embodiments, processor 2116 (and/or one or more other processors which eNB 2110 may comprise) may be a baseband processor.

[00207] Returning to **Fig. 22**, an apparatus of eNB 2110 (or another eNB or base station), which may be operable to communicate with one or more UEs on a wireless network, may comprise hardware processing circuitry 2200. In some embodiments, hardware processing circuitry 2200 may comprise one or more antenna ports 2205 operable to provide various transmissions over a wireless communication channel (such as wireless communication channel 2150). Antenna ports 2205 may be coupled to one or more antennas 2207 (which may be antennas 2105). In some embodiments, hardware processing circuitry 2200 may incorporate antennas 2207, while in other embodiments, hardware processing circuitry 2200 may merely be coupled to antennas 2207.

[00208] Antenna ports 2205 and antennas 2207 may be operable to provide signals from an eNB to a wireless communications channel and/or a UE, and may be operable to provide signals from a UE and/or a wireless communications channel to an eNB. For example, antenna ports 2205 and antennas 2207 may be operable to provide transmissions from eNB 2110 to wireless communication channel 2150 (and from there to UE 2130, or to another UE). Similarly, antennas 2207 and antenna ports 2205 may be operable to provide transmissions from a wireless communication channel 2150 (and beyond that, from UE 2130, or another UE) to eNB 2110.

[00209] Hardware processing circuitry 2200 may comprise various circuitries operable in accordance with the various embodiments discussed herein. With reference to **Fig. 22**, hardware processing circuitry 2200 may comprise a first circuitry 2210, a second circuitry 2220, a third circuitry 2230, and/or a fourth circuitry 2240.

[00210] In some embodiments of hardware processing circuitry 2200, first circuitry 2210 may be operable to establish a subframe configuration comprising one or more OFDM symbols for one of: UL transmission, or DL transmission. Second circuitry 2220 may be operable to allocate one or more PCRS REs to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies. First circuitry 2210 may provide information regarding the subframe configuration to second circuitry 2220 via an interface 2215.

[00211] In some embodiments, the one or more OFDM symbols may be for data channel transmission. For some embodiments, the one or more OFDM symbols may have indices from 3 through 13 within a OFDM subframe comprising symbols which may having indices from 0 through 13. In some embodiments, the one or more subcarrier frequencies may be distributed substantially equally across a set of 48 subcarrier frequencies. For some embodiments, the one or more subcarrier frequencies may be distributed substantially about a center of a set of 48 subcarrier frequencies.

[00212] In some embodiments, third circuitry 2230 may be operable to unmap the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies. The one or more OFDM symbols may be for UL transmission. Second circuitry 2220 may provide information regarding the allocation of PCRS REs to third circuitry 2230 via an interface 2224.

[00213] For some embodiments, fourth circuitry 2240 may be operable to map the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies. The one or more OFDM symbols are for DL transmission. Second circuitry 2220 may provide information regarding the allocation of PCRS REs to fourth circuitry 2240 via an interface 2222.

[00214] In some embodiments, second circuitry 2220 may be operable to allocate one or more DMRS REs corresponding to the one or more subcarrier frequencies. The one or more DMRS REs may carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies. The PCRS signal may be the same as the DMRS signal.

[00215] For some embodiments, second circuitry 2220 may be operable to allocate one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies. The one or more PCRS may correspond with a first antenna port, and the one or more additional PCRS may correspond with a second antenna port.

[00216] In some embodiments, the one or more PCRS REs may include a first set of PCRS REs at a first subcarrier frequency and corresponding with a first antenna port, and the one or more PCRS REs may include a second set of PCRS REs at a second subcarrier frequency and corresponding with a second antenna port. For some embodiments, the first subcarrier frequency and the second subcarrier frequency may be within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may be spaced from the first subcarrier frequency by one of: 14 subcarrier frequencies, or 15

subcarrier frequencies. In some embodiments, the first subcarrier frequency may have an index of 16 within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may have an index of 31 within the set of subcarrier frequencies.

[00217] For some embodiments, the first subcarrier frequency may have an index of 23 within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may have an index of 24 within the set of subcarrier frequencies. In some embodiments, the first subcarrier frequency may have an index of 16 within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may have an index of 32 within the set of subcarrier frequencies. For some embodiments, the one or more PCRS REs may include a third set of PCRS REs at a third subcarrier frequency and corresponding with a third antenna port.

[00218] In some embodiments, the first subcarrier frequency may have an index of 16 within a set of subcarrier frequencies having indices from 0 through 47, the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies, and the third subcarrier frequency has an index of 40 within the set of subcarrier frequencies. For some embodiments, the first subcarrier frequency may have an index of 23 within a set of subcarrier frequencies having indices from 0 through 47, the second subcarrier frequency may have an index of 24 within the set of subcarrier frequencies; and the third subcarrier frequency may have an index of 36 within the set of subcarrier frequencies.

[00219] In some embodiments of hardware processing circuitry 2200, first circuitry 2210 may be operable to establish a subframe configuration comprising one or more OFDM symbols for UL transmission. Second circuitry 2220 may be operable to unmap one or more PCRS REs carrying a PCRS signal for at least part of the one or more OFDM symbols at a subcarrier frequency. The one or more PCRS REs may be periodically spaced among the one or more OFDM symbols.

[00220] In some embodiments, the one or more PCRS REs may have odd indices among the OFDM symbols. For some embodiments, the one or more PCRS REs may have even indices among the OFDM symbols. In some embodiments, the one or more OFDM symbols may have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00221] For some embodiments, third circuitry 2230 may be operable to unmap one or more additional PCRS REs carrying an additional PCRS signal. The one or more PCRS REs may have odd indices among the OFDM symbols, and the one or more additional PCRS REs may have even indices among the OFDM symbols.

[00222] In some embodiments, third circuitry 2230 may be operable to unmap one or more additional PCRS REs carrying an additional PCRS signal for at least part of the one or more OFDM symbols at an additional subcarrier frequency. The one or more PCRS REs may be periodically spaced among the one or more OFDM symbols.

[00223] For some embodiments, the subcarrier frequency may have an index of X within a first set of N subcarrier frequencies having indices from 0 through N-1, and an additional subcarrier frequency may have the index of X within a second set of N subcarrier frequencies having indices from 0 through N-1, the second set of N subcarrier frequencies being adjacent to the first set of N subcarrier frequencies. In some embodiments, the one or more PCRS REs may have even indices among the OFDM symbols, and the one or more PCRS REs may have odd indices among the OFDM symbols.

[00224] In some embodiments of hardware processing circuitry 2200, first circuitry 2210 may be operable to establish a subframe configuration comprising a plurality of OFDM symbols for UL transmission. Third circuitry 2230 may be operable to unmap a first set of one or more REs carrying a primary PCRS signal for a first portion of the one or more OFDM symbols at a subcarrier frequency, and may be operable to unmap a second set of one or more REs carrying a secondary PCRS signal for a second portion of the one or more OFDM symbols at the subcarrier frequency. The first portion of the one or more OFDM symbols may have even symbol indices, and the second portion of the one or more OFDM symbols may have odd symbol indices.

[00225] In some embodiments, the first set of one or more REs may correspond with a primary PCRS antenna port, and the second set of one or more REs may correspond with a secondary PCRS antenna port different from the primary PCRS antenna port. For some embodiments, a port number of the primary PCRS antenna port may be greater than a port number of the secondary PCRS antenna port. In some embodiments, a port number of the primary PCRS antenna port may be less than a port number of the secondary PCRS antenna port.

[00226] For some embodiments, the primary PCRS antenna port and secondary PCRS antenna port may be indicated in one of: a DCI transmission, or a higher-layer signaling transmission. In some embodiments, indices of the one or more REs carrying the primary PCRS signal may be predetermined based upon a port number of the primary antenna port, and indices of the one or more REs carrying the secondary PCRS signal may be predetermined based upon a port number of the secondary antenna port.

[00227] In some embodiments, third circuitry 2230 may be operable to unmap an additional RE carrying a DMRS for one or more additional OFDM symbols at the subcarrier frequency. The additional RE may correspond with a DMRS antenna port.

[00228] For some embodiments, the DMRS antenna port may be one of: a primary PCRS antenna port corresponding with the first set of one or more REs; or a secondary PCRS antenna port corresponding with the second set of one or more REs.

[00229] In some embodiments, third circuitry 2230 may be operable to unmap one or more additional REs carrying one or more respectively corresponding DMRSes for one or more additional OFDM symbols. The subcarrier frequency may be within a set of 48 subcarrier frequencies, and one or more additional OFDM symbols are mapped to one or more of the set of 48 subcarrier frequencies.

[00230] For some embodiments, a primary PCRS antenna port corresponding with the first set of one or more REs may be determined from one of: a lowest antenna port corresponding with the one or more DMRSes, or a highest antenna port corresponding with the one or more DMRSes. In some embodiments, a primary PCRS antenna port may corresponding with the first set of one or more REs may be determined from an antenna port corresponding with one of the DMRSes at the subcarrier frequency.

[00231] In some embodiments, first circuitry 2210, second circuitry 2220, third circuitry 2230, and/or fourth circuitry 2240 may be implemented as separate circuitries. In other embodiments, first circuitry 2210, second circuitry 2220, third circuitry 2230, and/or fourth circuitry 2240 may be combined and implemented together in a circuitry without altering the essence of the embodiments.

[00232] **Fig. 23** illustrates hardware processing circuitries for a UE for PCRS, in accordance with some embodiments of the disclosure. With reference to **Fig. 21**, a UE may include various hardware processing circuitries discussed herein (such as hardware processing circuitry 2300 of **Fig. 23**), which may in turn comprise logic devices and/or circuitry operable to perform various operations. For example, in **Fig. 21**, UE 2130 (or various elements or components therein, such as hardware processing circuitry 2140, or combinations of elements or components therein) may include part of, or all of, these hardware processing circuitries.

[00233] In some embodiments, one or more devices or circuitries within these hardware processing circuitries may be implemented by combinations of software-configured elements and/or other hardware elements. For example, processor 2136 (and/or one or more other processors which UE 2130 may comprise), memory 2138, and/or other elements or

components of UE 2130 (which may include hardware processing circuitry 2140) may be arranged to perform the operations of these hardware processing circuitries, such as operations described herein with reference to devices and circuitry within these hardware processing circuitries. In some embodiments, processor 2136 (and/or one or more other processors which UE 2130 may comprise) may be a baseband processor.

[00234] Returning to **Fig. 23**, an apparatus of UE 2130 (or another UE or mobile handset), which may be operable to communicate with one or more eNBs on a wireless network, may comprise hardware processing circuitry 2300. In some embodiments, hardware processing circuitry 2300 may comprise one or more antenna ports 2305 operable to provide various transmissions over a wireless communication channel (such as wireless communication channel 2150). Antenna ports 2305 may be coupled to one or more antennas 2307 (which may be antennas 2125). In some embodiments, hardware processing circuitry 2300 may incorporate antennas 2307, while in other embodiments, hardware processing circuitry 2300 may merely be coupled to antennas 2307.

[00235] Antenna ports 2305 and antennas 2307 may be operable to provide signals from a UE to a wireless communications channel and/or an eNB, and may be operable to provide signals from an eNB and/or a wireless communications channel to a UE. For example, antenna ports 2305 and antennas 2307 may be operable to provide transmissions from UE 2130 to wireless communication channel 2150 (and from there to eNB 2110, or to another eNB). Similarly, antennas 2307 and antenna ports 2305 may be operable to provide transmissions from a wireless communication channel 2150 (and beyond that, from eNB 2110, or another eNB) to UE 2130.

[00236] Hardware processing circuitry 2300 may comprise various circuitries operable in accordance with the various embodiments discussed herein. With reference to **Fig. 23**, hardware processing circuitry 2300 may comprise a first circuitry 2310, a second circuitry 2320, a third circuitry 2330, and/or a fourth circuitry 2340.

[00237] In some embodiments of hardware processing circuitry 2300, first circuitry 2310 may be operable to establish a subframe configuration comprising one or more OFDM symbols for one of: UL transmission, or DL transmission. Second circuitry 2320 may be operable to allocate one or more PCRS REs to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies. First circuitry 2310 may provide information regarding the subframe configuration to second circuitry 2320 via an interface 2315.

[00238] In some embodiments, the one or more OFDM symbols may be for data channel transmission. For some embodiments, the one or more OFDM symbols may have indices from 3 through 13 within a OFDM subframe comprising symbols which may having indices from 0 through 13. In some embodiments, the one or more subcarrier frequencies may be distributed substantially equally across a set of 48 subcarrier frequencies. For some embodiments, the one or more subcarrier frequencies may be distributed substantially about a center of a set of 48 subcarrier frequencies.

[00239] In some embodiments, third circuitry 2330 may be operable to map the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies. The one or more OFDM symbols may be for UL transmission. Second circuitry 2320 may provide information regarding the allocation of PCRS REs to third circuitry 2330 via an interface 2322.

[00240] For some embodiments, fourth circuitry 2340 may be operable to unmap the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies. The one or more OFDM symbols may be for DL transmission. Second circuitry 2320 may provide information regarding the allocation of PCRS REs to fourth circuitry 2340 via an interface 2324.

[00241] In some embodiments, second circuitry 2320 may be operable to allocate one or more DMRS REs corresponding to the one or more subcarrier frequencies. The one or more DMRS REs may carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies, and the PCRS signal is the same as the DMRS signal.

[00242] For some embodiments, second circuitry 2320 may be operable to allocate one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies. The one or more PCRS may correspond with a first antenna port, and the one or more additional PCRS may correspond with a second antenna port.

[00243] In some embodiments, the one or more PCRS REs may include a first set of PCRS REs at a first subcarrier frequency and corresponding with a first antenna port, and the one or more PCRS REs may include a second set of PCRS REs at a second subcarrier frequency and corresponding with a second antenna port. For some embodiments, the first subcarrier frequency and the second subcarrier frequency may be within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may be spaced from the first subcarrier frequency by one of: 14 subcarrier frequencies, or 15

subcarrier frequencies. In some embodiments, the first subcarrier frequency may have an index of 16 within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may have an index of 31 within the set of subcarrier frequencies.

[00244] For some embodiments, the first subcarrier frequency may have an index of 23 within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may have an index of 24 within the set of subcarrier frequencies. In some embodiments, the first subcarrier frequency may have an index of 16 within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may have an index of 32 within the set of subcarrier frequencies. For some embodiments, the one or more PCRS REs may include a third set of PCRS REs at a third subcarrier frequency and corresponding with a third antenna port.

[00245] In some embodiments, the first subcarrier frequency may have an index of 16 within a set of subcarrier frequencies having indices from 0 through 47, the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies, and the third subcarrier frequency has an index of 40 within the set of subcarrier frequencies. For some embodiments, the first subcarrier frequency may have an index of 23 within a set of subcarrier frequencies having indices from 0 through 47, the second subcarrier frequency may have an index of 24 within the set of subcarrier frequencies; and the third subcarrier frequency may have an index of 36 within the set of subcarrier frequencies.

[00246] In some embodiments of hardware processing circuitry 2300, first circuitry 2310 may be operable to establish a subframe configuration comprising one or more OFDM symbols for UL transmission. Third circuitry 2330 may be operable to map one or more PCRS REs to carry a PCRS signal for at least part of the one or more OFDM symbols at a subcarrier frequency. The one or more PCRS REs may be periodically spaced among the one or more OFDM symbols.

[00247] In some embodiments, the one or more PCRS REs may have odd indices among the OFDM symbols. For some embodiments, the one or more PCRS REs may have even indices among the OFDM symbols. In some embodiments, the one or more OFDM symbols may have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00248] For some embodiments, third circuitry 2330 may be operable to map one or more additional PCRS REs to carry an additional PCRS signal. The one or more PCRS REs may have odd indices among the OFDM symbols. The one or more additional PCRS REs may have even indices among the OFDM symbols.

[00249] In some embodiments, third circuitry 2330 may be operable to map one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at an additional subcarrier frequency. The one or more PCRS REs may be periodically spaced among the one or more OFDM symbols.

[00250] For some embodiments, the subcarrier frequency may have an index of X within a first set of N subcarrier frequencies having indices from 0 through N-1, and an additional subcarrier frequency may have the index of X within a second set of N subcarrier frequencies having indices from 0 through N-1, the second set of N subcarrier frequencies being adjacent to the first set of N subcarrier frequencies. In some embodiments, the one or more PCRS REs may have even indices among the OFDM symbols, and the one or more PCRS REs may have odd indices among the OFDM symbols.

[00251] In some embodiments of hardware processing circuitry 2300, first circuitry 2310 may be operable to establish a subframe configuration comprising a plurality of OFDM symbols for UL transmission. Third circuitry 2330 may be operable to map a first set of one or more REs to carry a primary PCRS signal for a first portion of the one or more OFDM symbols at a subcarrier frequency, and may be operable to map a second set of one or more REs to carry a secondary PCRS signal for a second portion of the one or more OFDM symbols at the subcarrier frequency. The first portion of the one or more OFDM symbols may have even symbol indices, and the second portion of the one or more OFDM symbols may have odd symbol indices.

[00252] For some embodiments, the mapping may be enabled by a dual PCRS indicator carried by a DCI of a PDCCH. In some embodiments, the first set of one or more REs may correspond with a primary PCRS antenna port, and the second set of one or more REs may correspond with a secondary PCRS antenna port different from the primary PCRS antenna port. For some embodiments, a port number of the primary PCRS antenna port may be greater than a port number of the secondary PCRS antenna port. In some embodiments, a port number of the primary PCRS antenna port may be less than a port number of the secondary PCRS antenna port.

[00253] For some embodiments, the primary PCRS antenna port and secondary PCRS antenna port may be indicated in one of: a DCI transmission, or a higher-layer signaling transmission. In some embodiments, indices of the one or more REs carrying the primary PCRS signal may be predetermined based upon a port number of the primary antenna port, and indices of the one or more REs carrying the secondary PCRS signal may be predetermined based upon a port number of the secondary antenna port.

[00254] In some embodiments, third circuitry 2330 may be operable to map an additional RE to carry a DMRS for one or more additional OFDM symbols at the subcarrier frequency. The additional RE may correspond with a DMRS antenna port.

[00255] For some embodiments, the DMRS antenna port may be one of: a primary PCRS antenna port corresponding with the first set of one or more REs; or a secondary PCRS antenna port corresponding with the second set of one or more REs.

[00256] In some embodiments, third circuitry 2330 may be operable to map one or more additional REs to carry one or more respectively corresponding DMRSes for one or more additional OFDM symbols. The subcarrier frequency may be within a set of 48 subcarrier frequencies, and one or more additional OFDM symbols may be mapped to one or more of the set of 48 subcarrier frequencies.

[00257] For some embodiments, a primary PCRS antenna port corresponding with the first set of one or more REs may be determined from one of: a lowest antenna port corresponding with the one or more DMRSes, or a highest antenna port corresponding with the one or more DMRSes. In some embodiments, a primary PCRS antenna port may corresponding with the first set of one or more REs may be determined from an antenna port corresponding with one of the DMRSes at the subcarrier frequency.

[00258] In some embodiments, first circuitry 2310, second circuitry 2320, third circuitry 2330, and/or fourth circuitry 2340 may be implemented as separate circuitries. In other embodiments, first circuitry 2310, second circuitry 2320, third circuitry 2330, and fourth circuitry 2340 may be combined and implemented together in a circuitry without altering the essence of the embodiments.

[00259] **Figs. 24-26** illustrate methods for an eNB for PCRS, in accordance with some embodiments of the disclosure. With reference to **Fig. 21**, various methods that may relate to eNB 2110 and hardware processing circuitry 2120 are discussed herein. Although the actions in method 2400 of **Fig. 24**, method 2500 of **Fig. 25**, and method 2600 of **Fig. 26** are shown in a particular order, the order of the actions can be modified. Thus, the illustrated embodiments can be performed in a different order, and some actions may be performed in parallel. Some of the actions and/or operations listed in **Figs. 24, 25, and 26** are optional in accordance with certain embodiments. The numbering of the actions presented is for the sake of clarity and is not intended to prescribe an order of operations in which the various actions must occur. Additionally, operations from the various flows may be utilized in a variety of combinations.

[00260] Moreover, in some embodiments, machine readable storage media may have executable instructions that, when executed, cause eNB 2110 and/or hardware processing circuitry 2120 to perform an operation comprising the methods of **Figs. 24, 25, and 26**. Such machine readable storage media may include any of a variety of storage media, like magnetic storage media (e.g., magnetic tapes or magnetic disks), optical storage media (e.g., optical discs), electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any other tangible storage media or non-transitory storage media.

[00261] In some embodiments, an apparatus may comprise means for performing various actions and/or operations of the methods of **Figs. 24, 25, and 26**.

[00262] Returning to **Fig. 24**, various methods may be in accordance with the various embodiments discussed herein. A method 2400 may comprise an establishing 2410 and an allocating 2415. Method 2400 may also comprise an unmapping 2420, a mapping 2430, an allocating 2440, and/or an allocating 2450.

[00263] In establishing 2410, a subframe configuration may be established comprising one or more OFDM symbols for one of: UL transmission, or DL transmission. In allocating 2415, one or more PCRS REs may be allocated to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.

[00264] In some embodiments, the one or more OFDM symbols may be for data channel transmission. For some embodiments, the one or more OFDM symbols may have indices from 3 through 13 within a OFDM subframe comprising symbols which may having indices from 0 through 13. In some embodiments, the one or more subcarrier frequencies may be distributed substantially equally across a set of 48 subcarrier frequencies. For some embodiments, the one or more subcarrier frequencies may be distributed substantially about a center of a set of 48 subcarrier frequencies.

[00265] In unmapping 2420, the one or more PCRS REs may be unmapped from at least part of the one or more OFDM symbols at one or more subcarrier frequencies. The one or more OFDM symbols may be for UL transmission.

[00266] In mapping 2430, the one or more PCRS REs may be mapped to at least part of the one or more OFDM symbols at one or more subcarrier frequencies. The one or more OFDM symbols may be for DL transmission.

[00267] In allocating 2440, one or more DMRS REs corresponding to the one or more subcarrier frequencies may be allocated. The one or more DMRS REs may carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the

OFDM subframe and at the one or more subcarrier frequencies. The PCRS signal may be the same as the DMRS signal.

[00268] In allocating 2450, one or more additional PCRS REs may be allocated to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies. The one or more PCRS may correspond with a first antenna port, and the one or more additional PCRS may correspond with a second antenna port.

[00269] In some embodiments, the one or more PCRS REs may include a first set of PCRS REs at a first subcarrier frequency and corresponding with a first antenna port, and the one or more PCRS REs may include a second set of PCRS REs at a second subcarrier frequency and corresponding with a second antenna port. For some embodiments, the first subcarrier frequency and the second subcarrier frequency may be within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may be spaced from the first subcarrier frequency by one of: 14 subcarrier frequencies, or 15 subcarrier frequencies. In some embodiments, the first subcarrier frequency may have an index of 16 within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may have an index of 31 within the set of subcarrier frequencies.

[00270] For some embodiments, the first subcarrier frequency may have an index of 23 within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may have an index of 24 within the set of subcarrier frequencies. In some embodiments, the first subcarrier frequency may have an index of 16 within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may have an index of 32 within the set of subcarrier frequencies. For some embodiments, the one or more PCRS REs may include a third set of PCRS REs at a third subcarrier frequency and corresponding with a third antenna port.

[00271] In some embodiments, the first subcarrier frequency may have an index of 16 within a set of subcarrier frequencies having indices from 0 through 47, the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies, and the third subcarrier frequency has an index of 40 within the set of subcarrier frequencies. For some embodiments, the first subcarrier frequency may have an index of 23 within a set of subcarrier frequencies having indices from 0 through 47, the second subcarrier frequency may have an index of 24 within the set of subcarrier frequencies; and the third subcarrier frequency may have an index of 36 within the set of subcarrier frequencies.

[00272] Returning to **Fig. 25**, various methods may be in accordance with the various embodiments discussed herein. A method 2500 may comprise an establishing 2510 and an unmapping 2515. Method 2500 may also comprise an unmapping 2520 and/or an unmapping 2530.

[00273] In establishing 2510, a subframe configuration comprising one or more OFDM symbols for UL transmission may be established. In unmapping 2515, one or more PCRS REs carrying a PCRS signal may be mapped for at least part of the one or more OFDM symbols at a subcarrier frequency. The one or more PCRS REs may be periodically spaced among the one or more OFDM symbols.

[00274] In some embodiments, the one or more PCRS REs may have odd indices among the OFDM symbols. For some embodiments, the one or more PCRS REs may have even indices among the OFDM symbols. In some embodiments, the one or more OFDM symbols may have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00275] In unmapping 2520, one or more additional PCRS REs carrying an additional PCRS signal may be mapped. The one or more PCRS REs may have odd indices among the OFDM symbols, and the one or more additional PCRS REs may have even indices among the OFDM symbols.

[00276] In unmapping 2530, one or more additional PCRS REs carrying an additional PCRS signal may be unmapped for at least part of the one or more OFDM symbols at an additional subcarrier frequency. The one or more PCRS REs may be periodically spaced among the one or more OFDM symbols.

[00277] For some embodiments, the subcarrier frequency may have an index of X within a first set of N subcarrier frequencies having indices from 0 through N-1, and an additional subcarrier frequency may have the index of X within a second set of N subcarrier frequencies having indices from 0 through N-1, the second set of N subcarrier frequencies being adjacent to the first set of N subcarrier frequencies. In some embodiments, the one or more PCRS REs may have even indices among the OFDM symbols, and the one or more PCRS REs may have odd indices among the OFDM symbols.

[00278] Returning to **Fig. 26**, various methods may be in accordance with the various embodiments discussed herein. A method 2600 may comprise an establishing 2610, an unmapping 2615, and an unmapping 2620. Method 2600 may also comprise an unmapping 2630 and/or an unmapping 2640.

[00279] In establishing 2610, a subframe configuration comprising a plurality of OFDM symbols may be established for UL transmission. In unmapping 2615, a first set of one or more REs carrying a primary PCRS signal may be unmapped for a first portion of the one or more OFDM symbols at a subcarrier frequency. In unmapping 2620, a second set of one or more REs carrying a secondary PCRS signal may be unmapped for a second portion of the one or more OFDM symbols at the subcarrier frequency. The first portion of the one or more OFDM symbols may have even symbol indices, and the second portion of the one or more OFDM symbols may have odd symbol indices.

[00280] In some embodiments, the first set of one or more REs may correspond with a primary PCRS antenna port, and the second set of one or more REs may correspond with a secondary PCRS antenna port different from the primary PCRS antenna port. For some embodiments, a port number of the primary PCRS antenna port may be greater than a port number of the secondary PCRS antenna port. In some embodiments, a port number of the primary PCRS antenna port may be less than a port number of the secondary PCRS antenna port.

[00281] For some embodiments, the primary PCRS antenna port and secondary PCRS antenna port may be indicated in one of: a DCI transmission, or a higher-layer signaling transmission. In some embodiments, indices of the one or more REs carrying the primary PCRS signal may be predetermined based upon a port number of the primary antenna port, and indices of the one or more REs carrying the secondary PCRS signal may be predetermined based upon a port number of the secondary antenna port.

[00282] In unmapping 2630, an additional RE carrying a DMRS may be unmapped for one or more additional OFDM symbols at the subcarrier frequency. The additional RE may correspond with a DMRS antenna port.

[00283] For some embodiments, the DMRS antenna port may be one of: a primary PCRS antenna port corresponding with the first set of one or more REs; or a secondary PCRS antenna port corresponding with the second set of one or more REs.

[00284] In unmapping 2640, unmap one or more additional REs carrying one or more respectively corresponding DMRSes for one or more additional OFDM symbols. The subcarrier frequency may be within a set of 48 subcarrier frequencies, and one or more additional OFDM symbols may be mapped to one or more of the set of 48 subcarrier frequencies.

[00285] For some embodiments, a primary PCRS antenna port corresponding with the first set of one or more REs may be determined from one of: a lowest antenna port

corresponding with the one or more DMRSEs, or a highest antenna port corresponding with the one or more DMRSEs. In some embodiments, a primary PCRS antenna port may corresponding with the first set of one or more REs may be determined from an antenna port corresponding with one of the DMRSEs at the subcarrier frequency.

[00286] **Figs. 27-29** illustrate methods for a UE for PCRS, in accordance with some embodiments of the disclosure. With reference to **Fig. 21**, methods that may relate to UE 2130 and hardware processing circuitry 2140 are discussed herein. Although the actions in the method 2700 of **Fig. 27**, method 2800 of **Fig. 28**, and method 2900 of **Fig. 29** are shown in a particular order, the order of the actions can be modified. Thus, the illustrated embodiments can be performed in a different order, and some actions may be performed in parallel. Some of the actions and/or operations listed in **Figs. 27, 28, and 29** are optional in accordance with certain embodiments. The numbering of the actions presented is for the sake of clarity and is not intended to prescribe an order of operations in which the various actions must occur. Additionally, operations from the various flows may be utilized in a variety of combinations.

[00287] Moreover, in some embodiments, machine readable storage media may have executable instructions that, when executed, cause UE 2130 and/or hardware processing circuitry 2140 to perform an operation comprising the methods of **Figs. 27, 28, and 29**. Such machine readable storage media may include any of a variety of storage media, like magnetic storage media (e.g., magnetic tapes or magnetic disks), optical storage media (e.g., optical discs), electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any other tangible storage media or non-transitory storage media.

[00288] In some embodiments, an apparatus may comprise means for performing various actions and/or operations of the methods of **Figs. 27, 28, and 29**.

[00289] Returning to **Fig. 27**, various methods may be in accordance with the various embodiments discussed herein. A method 2700 may comprise an establishing 2710 and an allocating 2715. Method 2700 may also comprise a mapping 2720, an unmapping 2730, an allocating 2740, and/or an allocating 2750.

[00290] In establishing 2710, a subframe configuration comprising one or more OFDM symbols for one of: UL transmission, or DL transmission. In allocating 2715, one or more PCRS REs may be allocated to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.

[00291] In some embodiments, the one or more OFDM symbols may be for data channel transmission. For some embodiments, the one or more OFDM symbols may have indices from 3 through 13 within a OFDM subframe comprising symbols which may having indices from 0 through 13. In some embodiments, the one or more subcarrier frequencies may be distributed substantially equally across a set of 48 subcarrier frequencies. For some embodiments, the one or more subcarrier frequencies may be distributed substantially about a center of a set of 48 subcarrier frequencies.

[00292] In mapping 2720, the one or more PCRS REs may be mapped to at least part of the one or more OFDM symbols at one or more subcarrier frequencies. The one or more OFDM symbols may be for UL transmission.

[00293] In unmapping 2730, the one or more PCRS REs may be unmapped from at least part of the one or more OFDM symbols at one or more subcarrier frequencies. The one or more OFDM symbols may be for DL transmission.

[00294] In allocating 2740, one or more DMRS REs corresponding to the one or more subcarrier frequencies may be allocated. The one or more DMRS REs may carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies, and the PCRS signal may be the same as the DMRS signal.

[00295] In allocating 2750, one or more additional PCRS REs may be allocated to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies. The one or more PCRS may correspond with a first antenna port, and the one or more additional PCRS may correspond with a second antenna port.

[00296] In some embodiments, the one or more PCRS REs may include a first set of PCRS REs at a first subcarrier frequency and corresponding with a first antenna port, and the one or more PCRS REs may include a second set of PCRS REs at a second subcarrier frequency and corresponding with a second antenna port. For some embodiments, the first subcarrier frequency and the second subcarrier frequency may be within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may be spaced from the first subcarrier frequency by one of: 14 subcarrier frequencies, or 15 subcarrier frequencies. In some embodiments, the first subcarrier frequency may have an index of 16 within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may have an index of 31 within the set of subcarrier frequencies.

[00297] For some embodiments, the first subcarrier frequency may have an index of 23 within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may have an index of 24 within the set of subcarrier frequencies. In some embodiments, the first subcarrier frequency may have an index of 16 within a set of subcarrier frequencies having indices from 0 through 47, and the second subcarrier frequency may have an index of 32 within the set of subcarrier frequencies. For some embodiments, the one or more PCRS REs may include a third set of PCRS REs at a third subcarrier frequency and corresponding with a third antenna port.

[00298] In some embodiments, the first subcarrier frequency may have an index of 16 within a set of subcarrier frequencies having indices from 0 through 47, the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies, and the third subcarrier frequency has an index of 40 within the set of subcarrier frequencies. For some embodiments, the first subcarrier frequency may have an index of 23 within a set of subcarrier frequencies having indices from 0 through 47, the second subcarrier frequency may have an index of 24 within the set of subcarrier frequencies; and the third subcarrier frequency may have an index of 36 within the set of subcarrier frequencies.

[00299] Returning to **Fig. 28**, various methods may be in accordance with the various embodiments discussed herein. A method 2800 may comprise an establishing 2810 and a mapping 2815. Method 2800 may also comprise a mapping 2820 and/or a mapping 2830.

[00300] In establishing 2810, a subframe configuration comprising one or more OFDM symbols for UL transmission may be established. In mapping 2815, one or more PCRS REs may be mapped to carry a PCRS signal for at least part of the one or more OFDM symbols at a subcarrier frequency. The one or more PCRS REs may be periodically spaced among the one or more OFDM symbols.

[00301] In some embodiments, the one or more PCRS REs may have odd indices among the OFDM symbols. For some embodiments, the one or more PCRS REs may have even indices among the OFDM symbols. In some embodiments, the one or more OFDM symbols may have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00302] In mapping 2820, one or more additional PCRS REs may be mapped to carry an additional PCRS signal. The one or more PCRS REs may have odd indices among the OFDM symbols, and the one or more additional PCRS REs have even indices among the OFDM symbols.

[00303] In mapping 2830, one or more additional PCRS REs may be mapped to carry an additional PCRS signal for at least part of the one or more OFDM symbols at an additional subcarrier frequency. The one or more PCRS REs may be periodically spaced among the one or more OFDM symbols.

[00304] For some embodiments, the subcarrier frequency may have an index of X within a first set of N subcarrier frequencies having indices from 0 through $N-1$, and an additional subcarrier frequency may have the index of X within a second set of N subcarrier frequencies having indices from 0 through $N-1$, the second set of N subcarrier frequencies being adjacent to the first set of N subcarrier frequencies. In some embodiments, the one or more PCRS REs may have even indices among the OFDM symbols, and the one or more PCRS REs may have odd indices among the OFDM symbols.

[00305] Returning to **Fig. 29**, various methods may be in accordance with the various embodiments discussed herein. A method 2900 may comprise an establishing 2910, a mapping 2915, and a mapping 2920. Method 2900 may also comprise a mapping 2930 and/or a mapping 2940.

[00306] In establishing 2910, a subframe configuration comprising a plurality of OFDM symbols for UL transmission may be established. In mapping 2915, a first set of one or more REs may be mapped to carry a primary PCRS signal for a first portion of the one or more OFDM symbols at a subcarrier frequency. In mapping 2920, a second set of one or more REs may be mapped to carry a secondary PCRS signal for a second portion of the one or more OFDM symbols at the subcarrier frequency. The first portion of the one or more OFDM symbols may have even symbol indices, and the second portion of the one or more OFDM symbols may have odd symbol indices.

[00307] For some embodiments, the mapping may be enabled by a dual PCRS indicator carried by a DCI of a PDCCH. In some embodiments, the first set of one or more REs may correspond with a primary PCRS antenna port, and the second set of one or more REs may correspond with a secondary PCRS antenna port different from the primary PCRS antenna port. For some embodiments, a port number of the primary PCRS antenna port may be greater than a port number of the secondary PCRS antenna port. In some embodiments, a port number of the primary PCRS antenna port may be less than a port number of the secondary PCRS antenna port.

[00308] For some embodiments, the primary PCRS antenna port and secondary PCRS antenna port may be indicated in one of: a DCI transmission, or a higher-layer signaling transmission. In some embodiments, indices of the one or more REs carrying the primary

PCRS signal may be predetermined based upon a port number of the primary antenna port, and indices of the one or more REs carrying the secondary PCRS signal may be predetermined based upon a port number of the secondary antenna port.

[00309] In mapping 2930, an additional RE may be mapped to carry a DMRS for one or more additional OFDM symbols at the subcarrier frequency. The additional RE may correspond with a DMRS antenna port.

[00310] For some embodiments, the DMRS antenna port may be one of: a primary PCRS antenna port corresponding with the first set of one or more REs; or a secondary PCRS antenna port corresponding with the second set of one or more REs.

[00311] In mapping 2940, one or more additional REs may be mapped to carry one or more respectively corresponding DMRSes for one or more additional OFDM symbols. The subcarrier frequency may be within a set of 48 subcarrier frequencies, and one or more additional OFDM symbols may be mapped to one or more of the set of 48 subcarrier frequencies.

[00312] For some embodiments, a primary PCRS antenna port corresponding with the first set of one or more REs may be determined from one of: a lowest antenna port corresponding with the one or more DMRSes, or a highest antenna port corresponding with the one or more DMRSes. In some embodiments, a primary PCRS antenna port may corresponding with the first set of one or more REs may be determined from an antenna port corresponding with one of the DMRSes at the subcarrier frequency.

[00313] **Fig. 30** illustrates example components of a UE device 3000, in accordance with some embodiments of the disclosure. In some embodiments, a UE device 3000 may include application circuitry 3002, baseband circuitry 3004, Radio Frequency (RF) circuitry 3006, front-end module (FEM) circuitry 3008, a low-power wake-up receiver (LP-WUR), and one or more antennas 3010, coupled together at least as shown. In some embodiments, the UE device 3000 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

[00314] The application circuitry 3002 may include one or more application processors. For example, the application circuitry 3002 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

[00315] The baseband circuitry 3004 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 3004 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 3006 and to generate baseband signals for a transmit signal path of the RF circuitry 3006. Baseband processing circuitry 3004 may interface with the application circuitry 3002 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 3006. For example, in some embodiments, the baseband circuitry 3004 may include a second generation (2G) baseband processor 3004A, third generation (3G) baseband processor 3004B, fourth generation (4G) baseband processor 3004C, and/or other baseband processor(s) 3004D for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 3004 (e.g., one or more of baseband processors 3004A-D) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 3006. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 3004 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 3004 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

[00316] In some embodiments, the baseband circuitry 3004 may include elements of a protocol stack such as, for example, elements of an EUTRAN protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or RRC elements. A central processing unit (CPU) 3004E of the baseband circuitry 3004 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 3004F. The audio DSP(s) 3004F may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the

baseband circuitry 3004 and the application circuitry 3002 may be implemented together such as, for example, on a system on a chip (SOC).

[00317] In some embodiments, the baseband circuitry 3004 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 3004 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 3004 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[00318] RF circuitry 3006 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 3006 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 3006 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 3008 and provide baseband signals to the baseband circuitry 3004. RF circuitry 3006 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 3004 and provide RF output signals to the FEM circuitry 3008 for transmission.

[00319] In some embodiments, the RF circuitry 3006 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 3006 may include mixer circuitry 3006A, amplifier circuitry 3006B and filter circuitry 3006C. The transmit signal path of the RF circuitry 3006 may include filter circuitry 3006C and mixer circuitry 3006A. RF circuitry 3006 may also include synthesizer circuitry 3006D for synthesizing a frequency for use by the mixer circuitry 3006A of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 3006A of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 3008 based on the synthesized frequency provided by synthesizer circuitry 3006D. The amplifier circuitry 3006B may be configured to amplify the down-converted signals and the filter circuitry 3006C may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 3004 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry

3006A of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[00320] In some embodiments, the mixer circuitry 3006A of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 3006D to generate RF output signals for the FEM circuitry 3008. The baseband signals may be provided by the baseband circuitry 3004 and may be filtered by filter circuitry 3006C. The filter circuitry 3006C may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[00321] In some embodiments, the mixer circuitry 3006A of the receive signal path and the mixer circuitry 3006A of the transmit signal path may include two or more mixers and may be arranged for quadrature down-conversion and/or up-conversion respectively. In some embodiments, the mixer circuitry 3006A of the receive signal path and the mixer circuitry 3006A of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 3006A of the receive signal path and the mixer circuitry 3006A may be arranged for direct down-conversion and/or direct up-conversion, respectively. In some embodiments, the mixer circuitry 3006A of the receive signal path and the mixer circuitry 3006A of the transmit signal path may be configured for super-heterodyne operation.

[00322] In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 3006 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 3004 may include a digital baseband interface to communicate with the RF circuitry 3006.

[00323] In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

[00324] In some embodiments, the synthesizer circuitry 3006D may be a fractional-N synthesizer or a fractional $N/N+1$ synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 3006D may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[00325] The synthesizer circuitry 3006D may be configured to synthesize an output frequency for use by the mixer circuitry 3006A of the RF circuitry 3006 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 3006D may be a fractional $N/N+1$ synthesizer.

[00326] In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 3004 or the applications processor 3002 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 3002.

[00327] Synthesizer circuitry 3006D of the RF circuitry 3006 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or $N+1$ (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[00328] In some embodiments, synthesizer circuitry 3006D may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (fLO). In some embodiments, the RF circuitry 3006 may include an IQ/polar converter.

[00329] FEM circuitry 3008 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 3010, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 3006 for further processing. FEM circuitry 3008 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission

provided by the RF circuitry 3006 for transmission by one or more of the one or more antennas 3010.

[00330] In some embodiments, the FEM circuitry 3008 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 3006). The transmit signal path of the FEM circuitry 3008 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 3006), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 3010).

[00331] In some embodiments, the UE 3000 comprises a plurality of power saving mechanisms. If the UE 3000 is in an RRC_Connected state, where it is still connected to the eNB as it expects to receive traffic shortly, then it may enter a state known as Discontinuous Reception Mode (DRX) after a period of inactivity. During this state, the device may power down for brief intervals of time and thus save power.

[00332] If there is no data traffic activity for an extended period of time, then the UE 3000 may transition off to an RRC_Idle state, where it disconnects from the network and does not perform operations such as channel quality feedback, handover, etc. The UE 3000 goes into a very low power state and it performs paging where again it periodically wakes up to listen to the network and then powers down again. Since the device might not receive data in this state, in order to receive data, it should transition back to RRC_Connected state.

[00333] An additional power saving mode may allow a device to be unavailable to the network for periods longer than a paging interval (ranging from seconds to a few hours). During this time, the device is totally unreachable to the network and may power down completely. Any data sent during this time incurs a large delay and it is assumed the delay is acceptable.

[00334] In addition, in various embodiments, an eNB device may include components substantially similar to one or more of the example components of UE device 3000 described herein.

[00335] It is pointed out that elements of any of the Figures herein having the same reference numbers and/or names as elements of any other Figure herein may, in various embodiments, operate or function in a manner similar those elements of the other Figure (without being limited to operating or functioning in such a manner).

[00336] Reference in the specification to "an embodiment," "one embodiment," "some embodiments," or "other embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least some embodiments, but not necessarily all embodiments. The various appearances of "an embodiment," "one embodiment," or "some embodiments" are not necessarily all referring to the same embodiments. If the specification states a component, feature, structure, or characteristic "may," "might," or "could" be included, that particular component, feature, structure, or characteristic is not required to be included. If the specification or claim refers to "a" or "an" element, that does not mean there is only one of the elements. If the specification or claims refer to "an additional" element, that does not preclude there being more than one of the additional element.

[00337] Furthermore, the particular features, structures, functions, or characteristics may be combined in any suitable manner in one or more embodiments. For example, a first embodiment may be combined with a second embodiment anywhere the particular features, structures, functions, or characteristics associated with the two embodiments are not mutually exclusive.

[00338] While the disclosure has been described in conjunction with specific embodiments thereof, many alternatives, modifications and variations of such embodiments will be apparent to those of ordinary skill in the art in light of the foregoing description. For example, other memory architectures e.g., Dynamic RAM (DRAM) may use the embodiments discussed. The embodiments of the disclosure are intended to embrace all such alternatives, modifications, and variations as to fall within the broad scope of the appended claims.

[00339] In addition, well known power/ground connections to integrated circuit (IC) chips and other components may or may not be shown within the presented figures, for simplicity of illustration and discussion, and so as not to obscure the disclosure. Further, arrangements may be shown in block diagram form in order to avoid obscuring the disclosure, and also in view of the fact that specifics with respect to implementation of such block diagram arrangements are highly dependent upon the platform within which the present disclosure is to be implemented (i.e., such specifics should be well within purview of one skilled in the art). Where specific details (e.g., circuits) are set forth in order to describe example embodiments of the disclosure, it should be apparent to one skilled in the art that the disclosure can be practiced without, or with variation of, these specific details. The description is thus to be regarded as illustrative instead of limiting.

[00340] The following examples pertain to further embodiments. Specifics in the examples may be used anywhere in one or more embodiments. All optional features of the apparatus described herein may also be implemented with respect to a method or process.

[00341] Example 1 provides apparatus of an Evolved Node B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: one or more processors to: establish a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or Downlink (DL) transmission; and allocate one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.

[00342] In example 2, the apparatus of example 1, wherein the one or more OFDM symbols are for data channel transmission.

[00343] In example 3, the apparatus of either of examples 1 or 2, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00344] In example 4, the apparatus of any of examples 1 through 3, wherein the one or more subcarrier frequencies are distributed substantially equally across a set of 48 subcarrier frequencies.

[00345] In example 5, the apparatus of any of examples 1 through 4, wherein the one or more subcarrier frequencies are distributed substantially about a center of a set of 48 subcarrier frequencies.

[00346] In example 6, the apparatus of any of examples 1 through 5, wherein the one or more processors are to: unmap the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for UL transmission.

[00347] In example 7, the apparatus of any of examples 1 through 6, wherein the one or more processors are to: map the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for DL transmission.

[00348] In example 8, the apparatus of any of examples 1 through 7, wherein the one or more processors are to: allocate one or more Demodulation Reference Signal (DMRS) REs corresponding to the one or more subcarrier frequencies, wherein the one or more DMRS REs carry one or more respectively corresponding DMRS signals at a symbol having an

index of 2 within the OFDM subframe and at the one or more subcarrier frequencies; and wherein the PCRS signal is the same as the DMRS signal.

[00349] In example 9, the apparatus of any of examples 1 through 8, wherein the one or more processors are to: allocate one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies, wherein the one or more PCRS correspond with a first antenna port; and wherein the one or more additional PCRS correspond with a second antenna port.

[00350] In example 10, the apparatus of any of examples 1 through 9, wherein the one or more PCRS REs include a first set of PCRS REs at a first subcarrier frequency and corresponding with a first antenna port, and wherein the one or more PCRS REs include a second set of PCRS REs at a second subcarrier frequency and corresponding with a second antenna port.

[00351] In example 11, the apparatus of example 10, wherein the first subcarrier frequency and the second subcarrier frequency are within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency is spaced from the first subcarrier frequency by one of: 14 subcarrier frequencies, or 15 subcarrier frequencies.

[00352] In example 12, the apparatus of either of examples 10 or 11, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies.

[00353] In example 13, the apparatus of any of examples 10 through 12, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies.

[00354] In example 14, the apparatus of any of examples 10 through 13, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 32 within the set of subcarrier frequencies.

[00355] In example 15, the apparatus of any of examples 55 through 14, wherein the one or more PCRS REs include a third set of PCRS REs at a third subcarrier frequency and corresponding with a third antenna port.

[00356] In example 16, the apparatus of example 15, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0

through 47; wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 40 within the set of subcarrier frequencies.

[00357] In example 17, the apparatus of either of examples 15 or 16, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 36 within the set of subcarrier frequencies.

[00358] In example 18, the apparatus of any of examples 1 through 17, comprising a transceiver circuitry for generating transmissions and processing transmissions.

[00359] Example 19 provides Evolved Node B (eNB) device comprising an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device, the eNB device including the apparatus of any of examples 1 through 18.

[00360] Example 20 provides a method comprising: establishing, for an Evolved Node-B (eNB), a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or Downlink (DL) transmission; and allocating one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.

[00361] In example 21, the method of example 20, wherein the one or more OFDM symbols are for data channel transmission.

[00362] In example 22, the method of either of examples 20 or 21, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00363] In example 23, the method of any of examples 20 through 22, wherein the one or more subcarrier frequencies are distributed substantially equally across a set of 48 subcarrier frequencies.

[00364] In example 24, the method of any of examples 20 through 23, wherein the one or more subcarrier frequencies are distributed substantially about a center of a set of 48 subcarrier frequencies.

[00365] In example 25, the method of any of examples 20 through 24, comprising: unmapping the one or more PCRS REs from at least part of the one or more OFDM symbols

at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for UL transmission.

[00366] In example 26, the method of any of examples 20 through 25, comprising: mapping the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for DL transmission.

[00367] In example 27, the method of any of examples 20 through 26, comprising: allocating one or more Demodulation Reference Signal (DMRS) REs corresponding to the one or more subcarrier frequencies, wherein the one or more DMRS REs carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies; and wherein the PCRS signal is the same as the DMRS signal.

[00368] In example 28, the method of any of examples 20 through 27, comprising: allocating one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies, wherein the one or more PCRS correspond with a first antenna port; and wherein the one or more additional PCRS correspond with a second antenna port.

[00369] In example 29, the method of any of examples 20 through 28, wherein the one or more PCRS REs include a first set of PCRS REs at a first subcarrier frequency and corresponding with a first antenna port, and wherein the one or more PCRS REs include a second set of PCRS REs at a second subcarrier frequency and corresponding with a second antenna port.

[00370] In example 30, the method of example 29, wherein the first subcarrier frequency and the second subcarrier frequency are within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency is spaced from the first subcarrier frequency by one of: 14 subcarrier frequencies, or 15 subcarrier frequencies.

[00371] In example 31, the method of either of examples 29 or 30, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies.

[00372] In example 32, the method of any of examples 29 through 31, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices

from 0 through 47; and wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies.

[00373] In example 33, the method of any of examples 29 through 32, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 32 within the set of subcarrier frequencies.

[00374] In example 34, the method of any of examples 20 through 33, wherein the one or more PCRS REs include a third set of PCRS REs at a third subcarrier frequency and corresponding with a third antenna port.

[00375] In example 35, the method of example 34, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 40 within the set of subcarrier frequencies.

[00376] In example 36, the method of either of examples 34 or 35, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 36 within the set of subcarrier frequencies.

[00377] Example 37 provides machine readable storage media having machine executable instructions stored thereon that, when executed, cause one or more processors to perform a method according to any of examples 20 through 36.

[00378] Example 38 provides apparatus of an Evolved Node B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: means for establishing a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or Downlink (DL) transmission; and means for allocating one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.

[00379] In example 39, the apparatus of example 38, wherein the one or more OFDM symbols are for data channel transmission.

[00380] In example 40, the apparatus of either of examples 38 or 39, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00381] In example 41, the apparatus of any of examples 38 through 40, wherein the one or more subcarrier frequencies are distributed substantially equally across a set of 48 subcarrier frequencies.

[00382] In example 42, the apparatus of any of examples 38 through 41, wherein the one or more subcarrier frequencies are distributed substantially about a center of a set of 48 subcarrier frequencies.

[00383] In example 43, the apparatus of any of examples 38 through 42, comprising: means for unmapping the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for UL transmission.

[00384] In example 44, the apparatus of any of examples 38 through 43, comprising: means for mapping the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for DL transmission.

[00385] In example 45, the apparatus of any of examples 38 through 44, comprising: means for allocating one or more Demodulation Reference Signal (DMRS) REs corresponding to the one or more subcarrier frequencies, wherein the one or more DMRS REs carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies; and wherein the PCRS signal is the same as the DMRS signal.

[00386] In example 46, the apparatus of any of examples 38 through 45, comprising: means for allocating one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies, wherein the one or more PCRS correspond with a first antenna port; and wherein the one or more additional PCRS correspond with a second antenna port.

[00387] In example 47, the apparatus of any of examples 38 through 46, wherein the one or more PCRS REs include a first set of PCRS REs at a first subcarrier frequency and corresponding with a first antenna port, and wherein the one or more PCRS REs include a second set of PCRS REs at a second subcarrier frequency and corresponding with a second antenna port.

[00388] In example 48, the apparatus of example 47, wherein the first subcarrier frequency and the second subcarrier frequency are within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency is spaced

from the first subcarrier frequency by one of: 14 subcarrier frequencies, or 15 subcarrier frequencies.

[00389] In example 49, the apparatus of either of examples 47 or 48, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies.

[00390] In example 50, the apparatus of any of examples 47 through 49, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies.

[00391] In example 51, the apparatus of any of examples 47 through 50, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 32 within the set of subcarrier frequencies.

[00392] In example 52, the apparatus of any of examples 38 through 51, wherein the one or more PCRS REs include a third set of PCRS REs at a third subcarrier frequency and corresponding with a third antenna port.

[00393] In example 53, the apparatus of example 52, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 40 within the set of subcarrier frequencies.

[00394] In example 54, the apparatus of either of examples 52 or 53, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 36 within the set of subcarrier frequencies.

[00395] Example 55 provides machine readable storage media having machine executable instructions that, when executed, cause one or more processors of an Evolved Node B (eNB) to perform an operation comprising: establish a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or Downlink (DL) transmission; and allocate one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS

signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.

[00396] In example 56, the machine readable storage media of example 55, wherein the one or more OFDM symbols are for data channel transmission.

[00397] In example 57, the machine readable storage media of either of examples 55 or 56, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00398] In example 58, the machine readable storage media of any of examples 55 through 57, wherein the one or more subcarrier frequencies are distributed substantially equally across a set of 48 subcarrier frequencies.

[00399] In example 59, the machine readable storage media of any of examples 55 through 58, wherein the one or more subcarrier frequencies are distributed substantially about a center of a set of 48 subcarrier frequencies.

[00400] In example 60, the machine readable storage media of any of examples 55 through 59, the operation comprising: unmap the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for UL transmission.

[00401] In example 61, the machine readable storage media of any of examples 55 through 60, the operation comprising: map the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for DL transmission.

[00402] In example 62, the machine readable storage media of any of examples 55 through 61, the operation comprising: allocate one or more Demodulation Reference Signal (DMRS) REs corresponding to the one or more subcarrier frequencies, wherein the one or more DMRS REs carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies; and wherein the PCRS signal is the same as the DMRS signal.

[00403] In example 63, the machine readable storage media of any of examples 55 through 62, the operation comprising: allocate one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies, wherein the one or more PCRS correspond with a first antenna port; and wherein the one or more additional PCRS correspond with a second antenna port.

[00404] In example 64, the machine readable storage media of any of examples 55 through 63, wherein the one or more PCRS REs include a first set of PCRS REs at a first subcarrier frequency and corresponding with a first antenna port, and wherein the one or more PCRS REs include a second set of PCRS REs at a second subcarrier frequency and corresponding with a second antenna port.

[00405] In example 65, the machine readable storage media of example 64, wherein the first subcarrier frequency and the second subcarrier frequency are within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency is spaced from the first subcarrier frequency by one of: 14 subcarrier frequencies, or 15 subcarrier frequencies.

[00406] In example 66, the machine readable storage media of either of examples 64 or 65, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies.

[00407] In example 67, the machine readable storage media of any of examples 64 through 66, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies.

[00408] In example 68, the machine readable storage media of any of examples 64 through 67, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 32 within the set of subcarrier frequencies.

[00409] In example 69, the machine readable storage media of any of examples 55 through 68, wherein the one or more PCRS REs include a third set of PCRS REs at a third subcarrier frequency and corresponding with a third antenna port.

[00410] In example 70, the machine readable storage media of example 69, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 40 within the set of subcarrier frequencies.

[00411] In example 71, the machine readable storage media of either of examples 69 or 70, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has

an index of 24 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 36 within the set of subcarrier frequencies.

[00412] Example 72 provides an apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: one or more processors to: establish a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or Downlink (DL) transmission; and allocate one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.

[00413] In example 73, the apparatus of example 72, wherein the one or more OFDM symbols are for data channel transmission.

[00414] In example 74, the apparatus of either of examples 72 or 73, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00415] In example 75, the apparatus of any of examples 72 through 74, wherein the one or more subcarrier frequencies are distributed substantially equally across a set of 48 subcarrier frequencies.

[00416] In example 76, the apparatus of any of examples 72 through 75, wherein the one or more subcarrier frequencies are distributed substantially about a center of a set of 48 subcarrier frequencies.

[00417] In example 77, the apparatus of any of examples 72 through 76, wherein the one or more processors are to: map the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for UL transmission.

[00418] In example 78, the apparatus of any of examples 72 through 77, wherein the one or more processors are to: unmap the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for DL transmission.

[00419] In example 79, the apparatus of any of examples 72 through 78, wherein the one or more processors are to: allocate one or more Demodulation Reference Signal (DMRS) REs corresponding to the one or more subcarrier frequencies, wherein the one or more DMRS REs carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies; and wherein the PCRS signal is the same as the DMRS signal.

[00420] In example 80, the apparatus of any of examples 72 through 79, wherein the one or more processors are to: allocate one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies, wherein the one or more PCRS correspond with a first antenna port; and wherein the one or more additional PCRS correspond with a second antenna port.

[00421] In example 81, the apparatus of any of examples 72 through 80, wherein the one or more PCRS REs include a first set of PCRS REs at a first subcarrier frequency and corresponding with a first antenna port, and wherein the one or more PCRS REs include a second set of PCRS REs at a second subcarrier frequency and corresponding with a second antenna port.

[00422] In example 82, the apparatus of example 81, wherein the first subcarrier frequency and the second subcarrier frequency are within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency is spaced from the first subcarrier frequency by one of: 14 subcarrier frequencies, or 15 subcarrier frequencies.

[00423] In example 83, the apparatus of either of examples 81 or 82, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies.

[00424] In example 84, the apparatus of any of examples 81 through 83, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies.

[00425] In example 85, the apparatus of any of examples 81 through 84, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 32 within the set of subcarrier frequencies.

[00426] In example 86, the apparatus of any of examples 72 through 85, wherein the one or more PCRS REs include a third set of PCRS REs at a third subcarrier frequency and corresponding with a third antenna port.

[00427] In example 87, the apparatus of example 86, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 31 within the set of

subcarrier frequencies; and wherein the third subcarrier frequency has an index of 40 within the set of subcarrier frequencies.

[00428] In example 88, the apparatus of either of examples 86 or 87, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 36 within the set of subcarrier frequencies.

[00429] In example 89, the apparatus of any of examples 72 through 88, comprising a transceiver circuitry for generating transmissions and processing transmissions.

[00430] Example 90 provides a User Equipment (UE) device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display, the UE device including the apparatus of any of examples 72 through 89.

[00431] Example 91 provides a method comprising: establishing, for a User Equipment (UE), a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or Downlink (DL) transmission; and allocating one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.

[00432] In example 92, the method of example 91, wherein the one or more OFDM symbols are for data channel transmission.

[00433] In example 93, the method of either of examples 91 or 92, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00434] In example 94, the method of any of examples 91 through 93, wherein the one or more subcarrier frequencies are distributed substantially equally across a set of 48 subcarrier frequencies.

[00435] In example 95, the method of any of examples 91 through 94, wherein the one or more subcarrier frequencies are distributed substantially about a center of a set of 48 subcarrier frequencies.

[00436] In example 96, the method of any of examples 91 through 95, comprising: mapping the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for UL transmission.

[00437] In example 97, the method of any of examples 91 through 96, comprising: unmapping the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for DL transmission.

[00438] In example 98, the method of any of examples 91 through 97, comprising: allocating one or more Demodulation Reference Signal (DMRS) REs corresponding to the one or more subcarrier frequencies, wherein the one or more DMRS REs carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies; and wherein the PCRS signal is the same as the DMRS signal.

[00439] In example 99, the method of any of examples 91 through 98, comprising: allocating one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies, wherein the one or more PCRS correspond with a first antenna port; and wherein the one or more additional PCRS correspond with a second antenna port.

[00440] In example 100, the method of any of examples 91 through 99, wherein the one or more PCRS REs include a first set of PCRS REs at a first subcarrier frequency and corresponding with a first antenna port, and wherein the one or more PCRS REs include a second set of PCRS REs at a second subcarrier frequency and corresponding with a second antenna port.

[00441] In example 101, the method of example 100, wherein the first subcarrier frequency and the second subcarrier frequency are within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency is spaced from the first subcarrier frequency by one of: 14 subcarrier frequencies, or 15 subcarrier frequencies.

[00442] In example 102, the method of either of examples 100 or 101, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies.

[00443] In example 103, the method of any of examples 100 through 102, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies.

[00444] In example 104, the method of any of examples 100 through 103, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 32 within the set of subcarrier frequencies.

[00445] In example 105, the method of any of examples 91 through 104, wherein the one or more PCRS REs include a third set of PCRS REs at a third subcarrier frequency and corresponding with a third antenna port.

[00446] In example 106, the method of example 105, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 40 within the set of subcarrier frequencies.

[00447] In example 107, the method of either of examples 105 or 106, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 36 within the set of subcarrier frequencies.

[00448] Example 108 provides machine readable storage media having machine executable instructions stored thereon that, when executed, cause one or more processors to perform a method according to any of examples 91 through 107.

[00449] Example 109 provides an apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: means for establishing a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or Downlink (DL) transmission; and means for allocating one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.

[00450] In example 110, the apparatus of example 109, wherein the one or more OFDM symbols are for data channel transmission.

[00451] In example 111, the apparatus of either of examples 109 or 110, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00452] In example 112, the apparatus of any of examples 109 through 111, wherein the one or more subcarrier frequencies are distributed substantially equally across a set of 48 subcarrier frequencies.

[00453] In example 113, the apparatus of any of examples 109 through 112, wherein the one or more subcarrier frequencies are distributed substantially about a center of a set of 48 subcarrier frequencies.

[00454] In example 114, the apparatus of any of examples 109 through 113, comprising: means for mapping the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for UL transmission.

[00455] In example 115, the apparatus of any of examples 109 through 114, comprising: means for unmapping the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for DL transmission.

[00456] In example 116, the apparatus of any of examples 109 through 115, comprising: means for allocating one or more Demodulation Reference Signal (DMRS) REs corresponding to the one or more subcarrier frequencies, wherein the one or more DMRS REs carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies; and wherein the PCRS signal is the same as the DMRS signal.

[00457] In example 117, the apparatus of any of examples 109 through 113, comprising: means for allocating one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies, wherein the one or more PCRS correspond with a first antenna port; and wherein the one or more additional PCRS correspond with a second antenna port.

[00458] In example 118, the apparatus of any of examples 109 through 117, wherein the one or more PCRS REs include a first set of PCRS REs at a first subcarrier frequency and corresponding with a first antenna port, and wherein the one or more PCRS REs include a second set of PCRS REs at a second subcarrier frequency and corresponding with a second antenna port.

[00459] In example 119, the apparatus of example 118, wherein the first subcarrier frequency and the second subcarrier frequency are within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency is spaced

from the first subcarrier frequency by one of: 14 subcarrier frequencies, or 15 subcarrier frequencies.

[00460] In example 120, the apparatus of either of examples 118 or 119, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies.

[00461] In example 121, the apparatus of any of examples 118 through 120, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies.

[00462] In example 122, the apparatus of any of examples 118 through 121, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 32 within the set of subcarrier frequencies.

[00463] In example 123, the apparatus of any of examples 109 through 122, wherein the one or more PCRS REs include a third set of PCRS REs at a third subcarrier frequency and corresponding with a third antenna port.

[00464] In example 124, the apparatus of example 123, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 40 within the set of subcarrier frequencies.

[00465] In example 125, the apparatus of either of examples 123 or 124, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 36 within the set of subcarrier frequencies.

[00466] Example 126 provides machine readable storage media having machine executable instructions that, when executed, cause one or more processors of a User Equipment (UE) to perform an operation comprising: establish a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or Downlink (DL) transmission; and allocate one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS

signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.

[00467] In example 127, the machine readable storage media of example 126, wherein the one or more OFDM symbols are for data channel transmission.

[00468] In example 128, the machine readable storage media of either of examples 126 or 127, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00469] In example 129, the machine readable storage media of any of examples 126 through 128, wherein the one or more subcarrier frequencies are distributed substantially equally across a set of 48 subcarrier frequencies.

[00470] In example 130, the machine readable storage media of any of examples 126 through 129, wherein the one or more subcarrier frequencies are distributed substantially about a center of a set of 48 subcarrier frequencies.

[00471] In example 131, the machine readable storage media of any of examples 126 through 130, the operation comprising: map the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for UL transmission.

[00472] In example 132, the machine readable storage media of any of examples 126 through 131, the operation comprising: unmap the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies, wherein the one or more OFDM symbols are for DL transmission.

[00473] In example 133, the machine readable storage media of any of examples 126 through 132, the operation comprising: allocate one or more Demodulation Reference Signal (DMRS) REs corresponding to the one or more subcarrier frequencies, wherein the one or more DMRS REs carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies; and wherein the PCRS signal is the same as the DMRS signal.

[00474] In example 134, the machine readable storage media of any of examples 126 through 133, the operation comprising: allocate one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies, wherein the one or more PCRS correspond with a first antenna port; and wherein the one or more additional PCRS correspond with a second antenna port.

[00475] In example 135, the machine readable storage media of any of examples 126 through 134, wherein the one or more PCRS REs include a first set of PCRS REs at a first subcarrier frequency and corresponding with a first antenna port, and wherein the one or more PCRS REs include a second set of PCRS REs at a second subcarrier frequency and corresponding with a second antenna port.

[00476] In example 136, the machine readable storage media of example 135, wherein the first subcarrier frequency and the second subcarrier frequency are within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency is spaced from the first subcarrier frequency by one of: 14 subcarrier frequencies, or 15 subcarrier frequencies.

[00477] In example 137, the machine readable storage media of either of examples 135 or 136, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies.

[00478] In example 138, the machine readable storage media of any of examples 135 through 137, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 24 within the set of subcarrier frequencies.

[00479] In example 139, the machine readable storage media of any of examples 135 through 138, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; and wherein the second subcarrier frequency has an index of 32 within the set of subcarrier frequencies.

[00480] In example 140, the machine readable storage media of any of examples 126 through 139, wherein the one or more PCRS REs include a third set of PCRS REs at a third subcarrier frequency and corresponding with a third antenna port.

[00481] In example 141, the machine readable storage media of example 140, wherein the first subcarrier frequency has an index of 16 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has an index of 31 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 40 within the set of subcarrier frequencies.

[00482] In example 142, the machine readable storage media of either of examples 140 or 141, wherein the first subcarrier frequency has an index of 23 within a set of subcarrier frequencies having indices from 0 through 47; wherein the second subcarrier frequency has

an index of 24 within the set of subcarrier frequencies; and wherein the third subcarrier frequency has an index of 36 within the set of subcarrier frequencies.

[00483] Example 143 provides an apparatus of an Evolved Node B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: one or more processors to: establish a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; and unmap one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) carrying a PCRS signal for at least part of the one or more OFDM symbols at a subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00484] In example 144, the apparatus of example 143, wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00485] In example 145, the apparatus of either of examples 143 or 144, wherein the one or more PCRS REs have even indices among the OFDM symbols.

[00486] In example 146, the apparatus of any of examples 143 through 145, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00487] In example 147, the apparatus of any of examples 143 through 146, wherein the one or more processors are to: unmap one or more additional PCRS REs carrying an additional PCRS signal, wherein the one or more PCRS REs have odd indices among the OFDM symbols; and wherein the one or more additional PCRS REs have even indices among the OFDM symbols.

[00488] In example 148, the apparatus of any of examples 143 through 147, wherein the one or more processors are to: unmap one or more additional PCRS REs carrying an additional PCRS signal for at least part of the one or more OFDM symbols at an additional subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00489] In example 149, the apparatus of example 148, wherein the subcarrier frequency has an index of X within a first set of N subcarrier frequencies having indices from 0 through N-1; and wherein an additional subcarrier frequency has the index of X within a second set of N subcarrier frequencies having indices from 0 through N-1, the second set of N subcarrier frequencies being adjacent to the first set of N subcarrier frequencies.

[00490] In example 150, the apparatus of example 149, wherein the one or more PCRS REs have even indices among the OFDM symbols; and wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00491] In example 151, the apparatus of any of examples 143 through 150, comprising a transceiver circuitry for generating transmissions and processing transmissions.

[00492] Example 152 provides an Evolved Node B (eNB) device comprising an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device, the eNB device including the apparatus of any of examples 143 through 151.

[00493] Example 153 provides a method comprising: establishing, for an Evolved Node-B (eNB), a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; and unmapping one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) carrying a PCRS signal for at least part of the one or more OFDM symbols at a subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00494] In example 154, the method of example 153, wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00495] In example 155, the method of either of examples 153 or 154, wherein the one or more PCRS REs have even indices among the OFDM symbols.

[00496] In example 156, the method of any of examples 153 through 155, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00497] In example 157, the method of any of examples 153 through 156, comprising: unmapping one or more additional PCRS REs carrying an additional PCRS signal, wherein the one or more PCRS REs have odd indices among the OFDM symbols; and wherein the one or more additional PCRS REs have even indices among the OFDM symbols.

[00498] In example 158, the method of any of examples 153 through 157, comprising: unmapping one or more additional PCRS REs carrying an additional PCRS signal for at least part of the one or more OFDM symbols at an additional subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00499] In example 159, the method of example 158, wherein the subcarrier frequency has an index of X within a first set of N subcarrier frequencies having indices from 0 through N-1; and wherein an additional subcarrier frequency has the index of X within a second set of

N subcarrier frequencies having indices from 0 through N-1, the second set of N subcarrier frequencies being adjacent to the first set of N subcarrier frequencies.

[00500] In example 160, the method of example 159, wherein the one or more PCRS REs have even indices among the OFDM symbols; and wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00501] Example 161 provides machine readable storage media having machine executable instructions stored thereon that, when executed, cause one or more processors to perform a method according to any of examples 153 through 160.

[00502] Example 162 provides an apparatus of an Evolved Node B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: means for establishing a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; and means for unmapping one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) carrying a PCRS signal for at least part of the one or more OFDM symbols at a subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00503] In example 163, the apparatus of example 162, wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00504] In example 164, the apparatus of either of examples 162 or 163, wherein the one or more PCRS REs have even indices among the OFDM symbols.

[00505] In example 165, the apparatus of any of examples 162 through 164, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00506] In example 166, the apparatus of any of examples 162 through 165, comprising: means for unmapping one or more additional PCRS REs carrying an additional PCRS signal, wherein the one or more PCRS REs have odd indices among the OFDM symbols; and wherein the one or more additional PCRS REs have even indices among the OFDM symbols.

[00507] In example 167, the apparatus of any of examples 162 through 166, comprising: means for unmapping one or more additional PCRS REs carrying an additional PCRS signal for at least part of the one or more OFDM symbols at an additional subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00508] In example 168, the apparatus of example 167, wherein the subcarrier frequency has an index of X within a first set of N subcarrier frequencies having indices from 0 through $N-1$; and wherein an additional subcarrier frequency has the index of X within a second set of N subcarrier frequencies having indices from 0 through $N-1$, the second set of N subcarrier frequencies being adjacent to the first set of N subcarrier frequencies.

[00509] In example 169, the apparatus of example 168, wherein the one or more PCRS REs have even indices among the OFDM symbols; and wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00510] Example 170 provides machine readable storage media having machine executable instructions that, when executed, cause one or more processors of an Evolved Node B (eNB) to perform an operation comprising: establish a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; and unmap one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) carrying a PCRS signal for at least part of the one or more OFDM symbols at a subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00511] In example 171, the machine readable storage media of example 170, wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00512] In example 172, the machine readable storage media of either of examples 170 or 171, wherein the one or more PCRS REs have even indices among the OFDM symbols.

[00513] In example 173, the machine readable storage media of any of examples 170 through 172, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00514] In example 174, the machine readable storage media of any of examples 170 through 173, the operation comprising: unmap one or more additional PCRS REs carrying an additional PCRS signal, wherein the one or more PCRS REs have odd indices among the OFDM symbols; and wherein the one or more additional PCRS REs have even indices among the OFDM symbols.

[00515] In example 175, the machine readable storage media of any of examples 170 through 174, the operation comprising: unmap one or more additional PCRS REs carrying an additional PCRS signal for at least part of the one or more OFDM symbols at an additional subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00516] In example 176, the machine readable storage media of example 175, wherein the subcarrier frequency has an index of X within a first set of N subcarrier frequencies having indices from 0 through N-1; and wherein an additional subcarrier frequency has the index of X within a second set of N subcarrier frequencies having indices from 0 through N-1, the second set of N subcarrier frequencies being adjacent to the first set of N subcarrier frequencies.

[00517] In example 177, the machine readable storage media of example 176, wherein the one or more PCRS REs have even indices among the OFDM symbols; and wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00518] Example 178 provides an apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: one or more processors to: establish a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; and map one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at a subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00519] In example 179, the apparatus of example 178, wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00520] In example 180, the apparatus of either of examples 178 or 179, wherein the one or more PCRS REs have even indices among the OFDM symbols.

[00521] In example 181, the apparatus of any of examples 178 through 180, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00522] In example 182, the apparatus of any of examples 178 through 181, wherein the one or more processors are to: map one or more additional PCRS REs to carry an additional PCRS signal, wherein the one or more PCRS REs have odd indices among the OFDM symbols; and wherein the one or more additional PCRS REs have even indices among the OFDM symbols.

[00523] In example 183, the apparatus of any of examples 178 through 182, wherein the one or more processors are to: map one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at an additional subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00524] In example 184, the apparatus of example 183, wherein the subcarrier frequency has an index of X within a first set of N subcarrier frequencies having indices from 0 through $N-1$; and wherein an additional subcarrier frequency has the index of X within a second set of N subcarrier frequencies having indices from 0 through $N-1$, the second set of N subcarrier frequencies being adjacent to the first set of N subcarrier frequencies.

[00525] In example 185, the apparatus of example 184, wherein the one or more PCRS REs have even indices among the OFDM symbols; and wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00526] In example 186, the apparatus of any of examples 178 through 185, comprising a transceiver circuitry for generating transmissions and processing transmissions.

[00527] Example 187 provides a User Equipment (UE) device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display, the UE device including the apparatus of any of examples 178 through 186.

[00528] Example 188 provides a method comprising: establishing, for a User Equipment (UE), a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; and mapping one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at a subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00529] In example 189, the method of example 188, wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00530] In example 190, the method of either of examples 188 or 189, wherein the one or more PCRS REs have even indices among the OFDM symbols.

[00531] In example 191, the method of any of examples 188 through 190, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00532] In example 192, the method of any of examples 188 through 191, comprising: mapping one or more additional PCRS REs to carry an additional PCRS signal, wherein the one or more PCRS REs have odd indices among the OFDM symbols; and wherein the one or more additional PCRS REs have even indices among the OFDM symbols.

[00533] In example 193, the method of any of examples 188 through 192, comprising: mapping one or more additional PCRS REs to carry an additional PCRS signal for at least

part of the one or more OFDM symbols at an additional subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00534] In example 194, the method of example 193, wherein the subcarrier frequency has an index of X within a first set of N subcarrier frequencies having indices from 0 through N-1; and wherein an additional subcarrier frequency has the index of X within a second set of N subcarrier frequencies having indices from 0 through N-1, the second set of N subcarrier frequencies being adjacent to the first set of N subcarrier frequencies.

[00535] In example 195, the method of example 194, wherein the one or more PCRS REs have even indices among the OFDM symbols; and wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00536] Example 196 provides machine readable storage media having machine executable instructions stored thereon that, when executed, cause one or more processors to perform a method according to any of examples 188 through 195.

[00537] Example 197 provides an apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: means for establishing a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; and means for mapping one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at a subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00538] In example 198, the apparatus of example 197, wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00539] In example 199, the apparatus of either of examples 197 or 198, wherein the one or more PCRS REs have even indices among the OFDM symbols.

[00540] In example 200, the apparatus of any of examples 197 through 199, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00541] In example 201, the apparatus of any of examples 197 through 200, comprising: means for mapping one or more additional PCRS REs to carry an additional PCRS signal, wherein the one or more PCRS REs have odd indices among the OFDM symbols; and wherein the one or more additional PCRS REs have even indices among the OFDM symbols.

[00542] In example 202, the apparatus of any of examples 197 through 201, comprising: means for mapping one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at an additional subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00543] In example 203, the apparatus of example 202, wherein the subcarrier frequency has an index of X within a first set of N subcarrier frequencies having indices from 0 through N-1; and wherein an additional subcarrier frequency has the index of X within a second set of N subcarrier frequencies having indices from 0 through N-1, the second set of N subcarrier frequencies being adjacent to the first set of N subcarrier frequencies.

[00544] In example 204, the apparatus of example 203, wherein the one or more PCRS REs have even indices among the OFDM symbols; and wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00545] Example 205 provides machine readable storage media having machine executable instructions that, when executed, cause one or more processors of a User Equipment (UE) to perform an operation comprising: establish a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; and map one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at a subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00546] In example 206, the machine readable storage media of example 205, wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00547] In example 207, the machine readable storage media of either of examples 205 or 206, wherein the one or more PCRS REs have even indices among the OFDM symbols.

[00548] In example 208, the machine readable storage media of any of examples 205 through 207, wherein the one or more OFDM symbols have indices from 3 through 13 within a OFDM subframe comprising symbols having indices from 0 through 13.

[00549] In example 209, the machine readable storage media of any of examples 205 through 208, the operation comprising: map one or more additional PCRS REs to carry an additional PCRS signal, wherein the one or more PCRS REs have odd indices among the OFDM symbols; and wherein the one or more additional PCRS REs have even indices among the OFDM symbols.

[00550] In example 210, the machine readable storage media of any of examples 205 through 209, the operation comprising: map one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at an additional subcarrier frequency, wherein the one or more PCRS REs are periodically spaced among the one or more OFDM symbols.

[00551] In example 211, the machine readable storage media of example 210, wherein the subcarrier frequency has an index of X within a first set of N subcarrier frequencies having indices from 0 through N-1; and wherein an additional subcarrier frequency has the index of X within a second set of N subcarrier frequencies having indices from 0 through N-1, the second set of N subcarrier frequencies being adjacent to the first set of N subcarrier frequencies.

[00552] In example 212, the machine readable storage media of example 211, wherein the one or more PCRS REs have even indices among the OFDM symbols; and wherein the one or more PCRS REs have odd indices among the OFDM symbols.

[00553] Example 213 provides an apparatus of an Evolved Node B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: one or more processors to: establish a subframe configuration comprising a plurality of Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; unmap a first set of one or more Resource Elements (REs) carrying a primary Phase Compensation Reference Signal (PCRS) signal for a first portion of the one or more OFDM symbols at a subcarrier frequency; and unmap a second set of one or more REs carrying a secondary PCRS signal for a second portion of the one or more OFDM symbols at the subcarrier frequency, wherein the first portion of the one or more OFDM symbols have even symbol indices; and wherein the second portion of the one or more OFDM symbols have odd symbol indices.

[00554] In example 214, the apparatus of example 213, wherein the first set of one or more REs corresponds with a primary PCRS antenna port; and wherein the second set of one or more REs corresponds with a secondary PCRS antenna port different from the primary PCRS antenna port.

[00555] In example 215, the apparatus of example 214, wherein a port number of the primary PCRS antenna port is greater than a port number of the secondary PCRS antenna port.

[00556] In example 216, the apparatus of either of examples 214 or 215, wherein a port number of the primary PCRS antenna port is less than a port number of the secondary PCRS antenna port.

[00557] In example 217, the apparatus of any of examples 214 through 216, wherein the primary PCRS antenna port and secondary PCRS antenna port are indicated in one of: a Downlink Control Information (DCI) transmission, or a higher-layer signaling transmission.

[00558] In example 218, the apparatus of any of examples 214 through 217, wherein indices of the one or more REs carrying the primary PCRS signal are predetermined based upon a port number of the primary antenna port; and wherein indices of the one or more REs carrying the secondary PCRS signal are predetermined based upon a port number of the secondary antenna port.

[00559] In example 219, the apparatus of any of examples 213 through 218, wherein the one or more processors are to: unmap an additional RE carrying a Demodulation Reference Signal (DMRS) for one or more additional OFDM symbols at the subcarrier frequency, wherein the additional RE corresponds with a DMRS antenna port.

[00560] In example 220, the apparatus of example 219, wherein the DMRS antenna port is one of: a primary PCRS antenna port corresponding with the first set of one or more REs; or a secondary PCRS antenna port corresponding with the second set of one or more REs.

[00561] In example 221, the apparatus of any of examples 213 through 220, wherein the one or more processors are to: unmap one or more additional REs carrying one or more respectively corresponding Demodulation Reference Signals (DMRSes) for one or more additional OFDM symbols, wherein the subcarrier frequency is within a set of 48 subcarrier frequencies; wherein one or more additional OFDM symbols are mapped to one or more of the set of 48 subcarrier frequencies.

[00562] In example 222, the apparatus of example 151, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from one of: a lowest antenna port corresponding with the one or more DMRSes, or a highest antenna port corresponding with the one or more DMRSes.

[00563] In example 223, the apparatus of either of examples 151 or 222, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from an antenna port corresponding with one of the DMRSes at the subcarrier frequency.

[00564] In example 224, the apparatus of any of examples 213 through 223, comprising a transceiver circuitry for generating transmissions and processing transmissions.

[00565] Example 225 provides an Evolved Node B (eNB) device comprising an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device, the eNB device including the apparatus of any of examples 213 through 224.

[00566] Example 226 provides a method comprising: establishing, for an Evolved Node-B, a subframe configuration comprising a plurality of Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; unmapping a first set of one or more Resource Elements (REs) carrying a primary Phase Compensation Reference Signal (PCRS) signal for a first portion of the one or more OFDM symbols at a subcarrier frequency; and unmapping a second set of one or more REs carrying a secondary PCRS signal for a second portion of the one or more OFDM symbols at the subcarrier frequency, wherein the first portion of the one or more OFDM symbols have even symbol indices; and wherein the second portion of the one or more OFDM symbols have odd symbol indices.

[00567] In example 227, the method of example 226, wherein the first set of one or more REs corresponds with a primary PCRS antenna port; and wherein the second set of one or more REs corresponds with a secondary PCRS antenna port different from the primary PCRS antenna port.

[00568] In example 228, the method of example 227, wherein a port number of the primary PCRS antenna port is greater than a port number of the secondary PCRS antenna port.

[00569] In example 229, the method of either of examples 227 or 228, wherein a port number of the primary PCRS antenna port is less than a port number of the secondary PCRS antenna port.

[00570] In example 230, the method of any of examples 227 through 229, wherein the primary PCRS antenna port and secondary PCRS antenna port are indicated in one of: a Downlink Control Information (DCI) transmission, or a higher-layer signaling transmission.

[00571] In example 231, the method of any of examples 227 through 230, wherein indices of the one or more REs carrying the primary PCRS signal are predetermined based upon a port number of the primary antenna port; and wherein indices of the one or more REs carrying the secondary PCRS signal are predetermined based upon a port number of the secondary antenna port.

[00572] In example 232, the method of any of examples 226 through 231, comprising: unmapping an additional RE carrying a Demodulation Reference Signal (DMRS) for one or

more additional OFDM symbols at the subcarrier frequency, wherein the additional RE corresponds with a DMRS antenna port.

[00573] In example 233, the method of example 232, wherein the DMRS antenna port is one of: a primary PCRS antenna port corresponding with the first set of one or more REs; or a secondary PCRS antenna port corresponding with the second set of one or more REs.

[00574] In example 234, the method of any of examples 226 through 233, comprising: unmapping one or more additional REs carrying one or more respectively corresponding Demodulation Reference Signals (DMRSes) for one or more additional OFDM symbols, wherein the subcarrier frequency is within a set of 48 subcarrier frequencies; wherein one or more additional OFDM symbols are mapped to one or more of the set of 48 subcarrier frequencies.

[00575] In example 235, the method of example 234, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from one of: a lowest antenna port corresponding with the one or more DMRSes, or a highest antenna port corresponding with the one or more DMRSes.

[00576] In example 236, the method of any of examples 234 through 235, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from an antenna port corresponding with one of the DMRSes at the subcarrier frequency.

[00577] Example 237 provides machine readable storage media having machine executable instructions stored thereon that, when executed, cause one or more processors to perform a method according to any of examples 234 through 236.

[00578] Example 238 provides an apparatus of an Evolved Node B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: means for establishing a subframe configuration comprising a plurality of Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; means for unmapping a first set of one or more Resource Elements (REs) carrying a primary Phase Compensation Reference Signal (PCRS) signal for a first portion of the one or more OFDM symbols at a subcarrier frequency; and unmapping a second set of one or more REs carrying a secondary PCRS signal for a second portion of the one or more OFDM symbols at the subcarrier frequency, wherein the first portion of the one or more OFDM symbols have even symbol indices; and wherein the second portion of the one or more OFDM symbols have odd symbol indices.

[00579] In example 239, the apparatus of example 238, wherein the first set of one or more REs corresponds with a primary PCRS antenna port; and wherein the second set of one

or more REs corresponds with a secondary PCRS antenna port different from the primary PCRS antenna port.

[00580] In example 240, the apparatus of example 239, wherein a port number of the primary PCRS antenna port is greater than a port number of the secondary PCRS antenna port.

[00581] In example 241, the apparatus of either of examples 239 or 240, wherein a port number of the primary PCRS antenna port is less than a port number of the secondary PCRS antenna port.

[00582] In example 242, the apparatus of any of examples 239 through 241, wherein the primary PCRS antenna port and secondary PCRS antenna port are indicated in one of: a Downlink Control Information (DCI) transmission, or a higher-layer signaling transmission.

[00583] In example 243, the apparatus of any of examples 239 through 242, wherein indices of the one or more REs carrying the primary PCRS signal are predetermined based upon a port number of the primary antenna port; and wherein indices of the one or more REs carrying the secondary PCRS signal are predetermined based upon a port number of the secondary antenna port.

[00584] In example 244, the apparatus of any of examples 238 through 243, comprising: means for unmapping an additional RE carrying a Demodulation Reference Signal (DMRS) for one or more additional OFDM symbols at the subcarrier frequency, wherein the additional RE corresponds with a DMRS antenna port.

[00585] In example 245, the apparatus of example 244, wherein the DMRS antenna port is one of: a primary PCRS antenna port corresponding with the first set of one or more REs; or a secondary PCRS antenna port corresponding with the second set of one or more REs.

[00586] In example 246, the apparatus of any of examples 238 through 245, comprising: means for unmapping one or more additional REs carrying one or more respectively corresponding Demodulation Reference Signals (DMRSes) for one or more additional OFDM symbols, wherein the subcarrier frequency is within a set of 48 subcarrier frequencies; wherein one or more additional OFDM symbols are mapped to one or more of the set of 48 subcarrier frequencies.

[00587] In example 247, the apparatus of example 246, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from one of: a lowest antenna port corresponding with the one or more DMRSes, or a highest antenna port corresponding with the one or more DMRSes.

[00588] In example 248, the apparatus of any of examples 246 through 247, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from an antenna port corresponding with one of the DMRSes at the subcarrier frequency.

[00589] Example 249 provides machine readable storage media having machine executable instructions that, when executed, cause one or more processors of an Evolved Node B (eNB) to perform an operation comprising: establish a subframe configuration comprising a plurality of Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; unmap a first set of one or more Resource Elements (REs) carrying a primary Phase Compensation Reference Signal (PCRS) signal for a first portion of the one or more OFDM symbols at a subcarrier frequency; and unmap a second set of one or more REs carrying a secondary PCRS signal for a second portion of the one or more OFDM symbols at the subcarrier frequency, wherein the first portion of the one or more OFDM symbols have even symbol indices; and wherein the second portion of the one or more OFDM symbols have odd symbol indices.

[00590] In example 250, the machine readable storage media of example 249, wherein the first set of one or more REs corresponds with a primary PCRS antenna port; and wherein the second set of one or more REs corresponds with a secondary PCRS antenna port different from the primary PCRS antenna port.

[00591] In example 251, the machine readable storage media of example 250, wherein a port number of the primary PCRS antenna port is greater than a port number of the secondary PCRS antenna port.

[00592] In example 252, the machine readable storage media of either of examples 250 or 251, wherein a port number of the primary PCRS antenna port is less than a port number of the secondary PCRS antenna port.

[00593] In example 253, the machine readable storage media of any of examples 250 through 252, wherein the primary PCRS antenna port and secondary PCRS antenna port are indicated in one of: a Downlink Control Information (DCI) transmission, or a higher-layer signaling transmission.

[00594] In example 254, the machine readable storage media of any of examples 250 through 253, wherein indices of the one or more REs carrying the primary PCRS signal are predetermined based upon a port number of the primary antenna port; and wherein indices of the one or more REs carrying the secondary PCRS signal are predetermined based upon a port number of the secondary antenna port.

[00595] In example 255, the machine readable storage media of any of examples 249 through 254, the operation comprising: unmap an additional RE carrying a Demodulation Reference Signal (DMRS) for one or more additional OFDM symbols at the subcarrier frequency, wherein the additional RE corresponds with a DMRS antenna port.

[00596] In example 256, the machine readable storage media of example 255, wherein the DMRS antenna port is one of: a primary PCRS antenna port corresponding with the first set of one or more REs; or a secondary PCRS antenna port corresponding with the second set of one or more REs.

[00597] In example 257, the machine readable storage media of any of examples 249 through 256, the operation comprising: unmap one or more additional REs carrying one or more respectively corresponding Demodulation Reference Signals (DMRSes) for one or more additional OFDM symbols, wherein the subcarrier frequency is within a set of 48 subcarrier frequencies; wherein one or more additional OFDM symbols are mapped to one or more of the set of 48 subcarrier frequencies.

[00598] In example 258, the machine readable storage media of example 257, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from one of: a lowest antenna port corresponding with the one or more DMRSes, or a highest antenna port corresponding with the one or more DMRSes.

[00599] In example 259, the machine readable storage media of any of examples 257 through 258, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from an antenna port corresponding with one of the DMRSes at the subcarrier frequency.

[00600] Example 260 provides an apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: one or more processors to: establish a subframe configuration comprising a plurality of Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; map a first set of one or more Resource Elements (REs) to carry a primary Phase Compensation Reference Signal (PCRS) signal for a first portion of the one or more OFDM symbols at a subcarrier frequency; and map a second set of one or more REs to carry a secondary PCRS signal for a second portion of the one or more OFDM symbols at the subcarrier frequency, wherein the first portion of the one or more OFDM symbols have even symbol indices; and wherein the second portion of the one or more OFDM symbols have odd symbol indices.

[00601] In example 261, the apparatus of example 260, wherein the mapping is enabled by a dual PCRS indicator carried by a Downlink Control Information (DCI) of a Physical Downlink Control Channel (PDCCH).

[00602] In example 262, the apparatus of either of examples 260 or 261, wherein the first set of one or more REs corresponds with a primary PCRS antenna port; and wherein the second set of one or more REs corresponds with a secondary PCRS antenna port different from the primary PCRS antenna port.

[00603] In example 263, the apparatus of example 262, wherein a port number of the primary PCRS antenna port is greater than a port number of the secondary PCRS antenna port.

[00604] In example 264, the apparatus of any of examples 262 through 263, wherein a port number of the primary PCRS antenna port is less than a port number of the secondary PCRS antenna port.

[00605] In example 265, the apparatus of any of examples 262 through 264, wherein the primary PCRS antenna port and secondary PCRS antenna port are indicated in one of: a Downlink Control Information (DCI) transmission, or a higher-layer signaling transmission.

[00606] In example 266, the apparatus of any of examples 262 through 265, wherein indices of the one or more REs carrying the primary PCRS signal are predetermined based upon a port number of the primary antenna port; and wherein indices of the one or more REs carrying the secondary PCRS signal are predetermined based upon a port number of the secondary antenna port.

[00607] In example 267, the apparatus of any of examples 260 through 266, wherein the one or more processors are to: map an additional RE to carry a Demodulation Reference Signal (DMRS) for one or more additional OFDM symbols at the subcarrier frequency, wherein the additional RE corresponds with a DMRS antenna port.

[00608] In example 268, the apparatus of example 267, wherein the DMRS antenna port is one of: a primary PCRS antenna port corresponding with the first set of one or more REs; or a secondary PCRS antenna port corresponding with the second set of one or more REs.

[00609] In example 269, the apparatus of any of examples 260 through 268, wherein the one or more processors are to: map one or more additional REs to carry one or more respectively corresponding Demodulation Reference Signals (DMRSes) for one or more additional OFDM symbols, wherein the subcarrier frequency is within a set of 48 subcarrier

frequencies; wherein one or more additional OFDM symbols are mapped to one or more of the set of 48 subcarrier frequencies.

[00610] In example 270, the apparatus of example 269, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from one of: a lowest antenna port corresponding with the one or more DMRSes, or a highest antenna port corresponding with the one or more DMRSes.

[00611] In example 271, the apparatus of either of examples 269 or 270, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from an antenna port corresponding with one of the DMRSes at the subcarrier frequency.

[00612] In example 272, the apparatus of any of examples 260 through 271, comprising a transceiver circuitry for generating transmissions and processing transmissions.

[00613] Example 273 provides a User Equipment (UE) device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display, the UE device including the apparatus of any of examples 260 through 272.

[00614] Example 274 provides a method comprising: establishing, for a User Equipment, a subframe configuration comprising a plurality of Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; mapping a first set of one or more Resource Elements (REs) to carry a primary Phase Compensation Reference Signal (PCRS) signal for a first portion of the one or more OFDM symbols at a subcarrier frequency; and mapping a second set of one or more REs to carry a secondary PCRS signal for a second portion of the one or more OFDM symbols at the subcarrier frequency, wherein the first portion of the one or more OFDM symbols have even symbol indices; and wherein the second portion of the one or more OFDM symbols have odd symbol indices.

[00615] In example 275, the method of example 274, wherein the mapping is enabled by a dual PCRS indicator carried by a Downlink Control Information (DCI) of a Physical Downlink Control Channel (PDCCH).

[00616] In example 276, the method of either of examples 274 or 275, wherein the first set of one or more REs corresponds with a primary PCRS antenna port; and wherein the second set of one or more REs corresponds with a secondary PCRS antenna port different from the primary PCRS antenna port.

[00617] In example 277, the method of example 276, wherein a port number of the primary PCRS antenna port is greater than a port number of the secondary PCRS antenna port.

[00618] In example 278, the method of either of examples 276 or 277, wherein a port number of the primary PCRS antenna port is less than a port number of the secondary PCRS antenna port.

[00619] In example 279, the method of any of examples 276 through 278, wherein the primary PCRS antenna port and secondary PCRS antenna port are indicated in one of: a Downlink Control Information (DCI) transmission, or a higher-layer signaling transmission.

[00620] In example 280, the method of any of examples 276 through 279, wherein indices of the one or more REs carrying the primary PCRS signal are predetermined based upon a port number of the primary antenna port; and wherein indices of the one or more REs carrying the secondary PCRS signal are predetermined based upon a port number of the secondary antenna port.

[00621] In example 281, the method of any of examples 274 through 280, comprising: mapping an additional RE to carry a Demodulation Reference Signal (DMRS) for one or more additional OFDM symbols at the subcarrier frequency, wherein the additional RE corresponds with a DMRS antenna port.

[00622] In example 282, the method of example 281, wherein the DMRS antenna port is one of: a primary PCRS antenna port corresponding with the first set of one or more REs; or a secondary PCRS antenna port corresponding with the second set of one or more REs.

[00623] In example 283, the method of any of examples 274 through 282, comprising: mapping one or more additional REs to carry one or more respectively corresponding Demodulation Reference Signals (DMRSes) for one or more additional OFDM symbols, wherein the subcarrier frequency is within a set of 48 subcarrier frequencies; wherein one or more additional OFDM symbols are mapped to one or more of the set of 48 subcarrier frequencies.

[00624] In example 284, the method of example 283, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from one of: a lowest antenna port corresponding with the one or more DMRSes, or a highest antenna port corresponding with the one or more DMRSes.

[00625] In example 285, the method of either of examples 283 or 284, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from an antenna port corresponding with one of the DMRSes at the subcarrier frequency.

[00626] Example 286 provides machine readable storage media having machine executable instructions stored thereon that, when executed, cause one or more processors to perform a method according to of any of examples 274 through 285.

[00627] Example 287 provides an apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: means for establishing a subframe configuration comprising a plurality of Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; means for mapping a first set of one or more Resource Elements (REs) to carry a primary Phase Compensation Reference Signal (PCRS) signal for a first portion of the one or more OFDM symbols at a subcarrier frequency; and means for mapping a second set of one or more REs to carry a secondary PCRS signal for a second portion of the one or more OFDM symbols at the subcarrier frequency, wherein the first portion of the one or more OFDM symbols have even symbol indices; and wherein the second portion of the one or more OFDM symbols have odd symbol indices.

[00628] In example 288, the apparatus of example 287, wherein the mapping is enabled by a dual PCRS indicator carried by a Downlink Control Information (DCI) of a Physical Downlink Control Channel (PDCCH).

[00629] In example 289, the apparatus of either of examples 287 or 288, wherein the first set of one or more REs corresponds with a primary PCRS antenna port; and wherein the second set of one or more REs corresponds with a secondary PCRS antenna port different from the primary PCRS antenna port.

[00630] In example 290, the apparatus of example 289, wherein a port number of the primary PCRS antenna port is greater than a port number of the secondary PCRS antenna port.

[00631] In example 291, the apparatus of either of examples 289 or 290, wherein a port number of the primary PCRS antenna port is less than a port number of the secondary PCRS antenna port.

[00632] In example 292, the apparatus of any of examples 289 through 291, wherein the primary PCRS antenna port and secondary PCRS antenna port are indicated in one of: a Downlink Control Information (DCI) transmission, or a higher-layer signaling transmission.

[00633] In example 293, the apparatus of any of examples 289 through 292, wherein indices of the one or more REs carrying the primary PCRS signal are predetermined based upon a port number of the primary antenna port; and wherein indices of the one or more REs carrying the secondary PCRS signal are predetermined based upon a port number of the secondary antenna port.

[00634] In example 294, the apparatus of any of examples 287 through 293, comprising: means for mapping an additional RE to carry a Demodulation Reference Signal

(DMRS) for one or more additional OFDM symbols at the subcarrier frequency, wherein the additional RE corresponds with a DMRS antenna port.

[00635] In example 295, the apparatus of example 294, wherein the DMRS antenna port is one of: a primary PCRS antenna port corresponding with the first set of one or more REs; or a secondary PCRS antenna port corresponding with the second set of one or more REs.

[00636] In example 296, the apparatus of any of examples 287 through 295, comprising: means for mapping one or more additional REs to carry one or more respectively corresponding Demodulation Reference Signals (DMRSes) for one or more additional OFDM symbols, wherein the subcarrier frequency is within a set of 48 subcarrier frequencies; wherein one or more additional OFDM symbols are mapped to one or more of the set of 48 subcarrier frequencies.

[00637] In example 297, the apparatus of example 296, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from one of: a lowest antenna port corresponding with the one or more DMRSes, or a highest antenna port corresponding with the one or more DMRSes.

[00638] In example 298, the apparatus of either of examples 296 or 297, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from an antenna port corresponding with one of the DMRSes at the subcarrier frequency.

[00639] Example 299 provides machine readable storage media having machine executable instructions that, when executed, cause one or more processors of a User Equipment (UE) to perform an operation comprising: establish a subframe configuration comprising a plurality of Orthogonal Frequency Division Multiplexing (OFDM) symbols for Uplink (UL) transmission; map a first set of one or more Resource Elements (REs) to carry a primary Phase Compensation Reference Signal (PCRS) signal for a first portion of the one or more OFDM symbols at a subcarrier frequency; and map a second set of one or more REs to carry a secondary PCRS signal for a second portion of the one or more OFDM symbols at the subcarrier frequency, wherein the first portion of the one or more OFDM symbols have even symbol indices; and wherein the second portion of the one or more OFDM symbols have odd symbol indices.

[00640] In example 300, the machine readable storage media of example 299, wherein the mapping is enabled by a dual PCRS indicator carried by a Downlink Control Information (DCI) of a Physical Downlink Control Channel (PDCCH).

[00641] In example 301, the machine readable storage media of either of examples 299 or 300, wherein the first set of one or more REs corresponds with a primary PCRS antenna port; and wherein the second set of one or more REs corresponds with a secondary PCRS antenna port different from the primary PCRS antenna port.

[00642] In example 302, the machine readable storage media of example 301, wherein a port number of the primary PCRS antenna port is greater than a port number of the secondary PCRS antenna port.

[00643] In example 303, the machine readable storage media of either of examples 301 or 302, wherein a port number of the primary PCRS antenna port is less than a port number of the secondary PCRS antenna port.

[00644] In example 304, the machine readable storage media of any of examples 301 through 303, wherein the primary PCRS antenna port and secondary PCRS antenna port are indicated in one of: a Downlink Control Information (DCI) transmission, or a higher-layer signaling transmission.

[00645] In example 305, the machine readable storage media of any of examples 301 through 304, wherein indices of the one or more REs carrying the primary PCRS signal are predetermined based upon a port number of the primary antenna port; and wherein indices of the one or more REs carrying the secondary PCRS signal are predetermined based upon a port number of the secondary antenna port.

[00646] In example 306, the machine readable storage media of any of examples 299 through 305, the operation comprising: map an additional RE to carry a Demodulation Reference Signal (DMRS) for one or more additional OFDM symbols at the subcarrier frequency, wherein the additional RE corresponds with a DMRS antenna port.

[00647] In example 307, the machine readable storage media of example 306, wherein the DMRS antenna port is one of: a primary PCRS antenna port corresponding with the first set of one or more REs; or a secondary PCRS antenna port corresponding with the second set of one or more REs.

[00648] In example 308, the machine readable storage media of any of examples 299 through 307, the operation comprising: map one or more additional REs to carry one or more respectively corresponding Demodulation Reference Signals (DMRSes) for one or more additional OFDM symbols, wherein the subcarrier frequency is within a set of 48 subcarrier frequencies; wherein one or more additional OFDM symbols are mapped to one or more of the set of 48 subcarrier frequencies.

[00649] In example 309, the machine readable storage media of example 308, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from one of: a lowest antenna port corresponding with the one or more DMRSes, or a highest antenna port corresponding with the one or more DMRSes.

[00650] In example 310, the machine readable storage media of either of examples 308 or 309, wherein a primary PCRS antenna port corresponding with the first set of one or more REs is determined from an antenna port corresponding with one of the DMRSes at the subcarrier frequency.

[00651] In example 311, the apparatus of any of examples 1 through 17, 72 through 88, 143 through 150, 178 through 185, 213 through 223, and 260 through 271, wherein the one or more processors comprise a baseband processor.

[00652] In example 312, the apparatus of any of examples 1 through 17, 72 through 88, 143 through 150, 178 through 185, 213 through 223, and 260 through 271, comprising a memory for storing instructions, the memory being coupled to the one or more processors.

[00653] In example 313, the apparatus of any of examples 1 through 17, 72 through 88, 143 through 150, 178 through 185, 213 through 223, and 260 through 271, comprising a transceiver circuitry for at least one of: generating transmissions, encoding transmissions, processing transmissions, or decoding transmissions.

[00654] In example 314, the apparatus of any of examples 1 through 17, 72 through 88, 143 through 150, 178 through 185, 213 through 223, and 260 through 271, comprising a transceiver circuitry for generating transmissions and processing transmissions.

[00655] An abstract is provided that will allow the reader to ascertain the nature and gist of the technical disclosure. The abstract is submitted with the understanding that it will not be used to limit the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

CLAIMS

We claim:

1. An apparatus of an Evolved Node-B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising:
 - one or more processors to:
 - establish a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or Downlink (DL) transmission; and
 - allocate one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.
2. The apparatus of claim 1,
 - wherein the one or more OFDM symbols are for data channel transmission.
3. The apparatus of either of claims 1 or 2, wherein the one or more processors are to:
 - unmap the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies,
 - wherein the one or more OFDM symbols are for UL transmission.
4. The apparatus of either of claims 1 or 2, wherein the one or more processors are to:
 - map the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies,
 - wherein the one or more OFDM symbols are for DL transmission.
5. The apparatus of either of claims 1 or 2, wherein the one or more processors are to:
 - allocate one or more Demodulation Reference Signal (DMRS) REs corresponding to the one or more subcarrier frequencies,
 - wherein the one or more DMRS REs carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies; and
 - wherein the PCRS signal is the same as the DMRS signal.

6. The apparatus of either of claims 1 or 2, wherein the one or more processors are to:
allocate one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies,
wherein the one or more PCRS correspond with a first antenna port; and
wherein the one or more additional PCRS correspond with a second antenna port.
7. Machine readable storage media having machine executable instructions that, when executed, cause one or more processors of an Evolved Node-B (eNB) to perform an operation comprising:
establish a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or Downlink (DL) transmission; and
allocate one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.
8. The machine readable storage media of claim 7,
wherein the one or more OFDM symbols are for data channel transmission.
9. The machine readable storage media of either of claims 7 or 8, the operation comprising:
unmap the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies,
wherein the one or more OFDM symbols are for UL transmission.
10. The machine readable storage media of either of claims 7 or 8, the operation comprising:
map the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies,
wherein the one or more OFDM symbols are for DL transmission.
11. The machine readable storage media of either of claims 7 or 8, the operation comprising:
allocate one or more Demodulation Reference Signal (DMRS) REs corresponding to the one or more subcarrier frequencies,

wherein the one or more DMRS REs carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies; and
wherein the PCRS signal is the same as the DMRS signal.

12. The machine readable storage media of either of claims 7 or 8, the operation comprising:
allocate one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies,
wherein the one or more PCRS correspond with a first antenna port; and
wherein the one or more additional PCRS correspond with a second antenna port.

13. An apparatus of a User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network, comprising:
one or more processors to:
establish a subframe configuration comprising one or more Orthogonal Frequency Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or Downlink (DL) transmission; and
allocate one or more Phase Compensation Reference Signal (PCRS) Resource Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM symbols at one or more subcarrier frequencies.

14. The apparatus of claim 13,
wherein the one or more OFDM symbols are for data channel transmission.

15. The apparatus of either of claims 13 or 14, wherein the one or more processors are to:
map the one or more PCRS REs to at least part of the one or more OFDM symbols at one or more subcarrier frequencies,
wherein the one or more OFDM symbols are for UL transmission.

16. The apparatus of either of claims 13 or 14, wherein the one or more processors are to:
unmap the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies,
wherein the one or more OFDM symbols are for DL transmission.

17. The apparatus of either of claims 13 or 14, wherein the one or more processors are to:
allocate one or more Demodulation Reference Signal (DMRS) REs corresponding to
the one or more subcarrier frequencies,
wherein the one or more DMRS REs carry one or more respectively corresponding
DMRS signals at a symbol having an index of 2 within the OFDM subframe and
at the one or more subcarrier frequencies; and
wherein the PCRS signal is the same as the DMRS signal.
18. The apparatus of either of claims 13 or 14, wherein the one or more processors are to:
allocate one or more additional PCRS REs to carry an additional PCRS signal for at
least part of the one or more OFDM symbols at one or more additional subcarrier
frequencies,
wherein the one or more PCRS correspond with a first antenna port; and
wherein the one or more additional PCRS correspond with a second antenna port.
19. Machine readable storage media having machine executable instructions that, when
executed, cause one or more processors of a User Equipment (UE) to perform an
operation comprising:
establish a subframe configuration comprising one or more Orthogonal Frequency
Division Multiplexing (OFDM) symbols for one of: Uplink (UL) transmission, or
Downlink (DL) transmission; and
allocate one or more Phase Compensation Reference Signal (PCRS) Resource
Elements (REs) to carry a PCRS signal for at least part of the one or more OFDM
symbols at one or more subcarrier frequencies.
20. The machine readable storage media of claim 19,
wherein the one or more OFDM symbols are for data channel transmission.
21. The machine readable storage media of either of claims 19 or 20, the operation
comprising:
map the one or more PCRS REs to at least part of the one or more OFDM symbols at
one or more subcarrier frequencies,
wherein the one or more OFDM symbols are for UL transmission.

22. The machine readable storage media of either of claims 19 or 20, the operation comprising:
- unmap the one or more PCRS REs from at least part of the one or more OFDM symbols at one or more subcarrier frequencies,
 - wherein the one or more OFDM symbols are for DL transmission.
23. The machine readable storage media of either of claims 19 or 20, the operation comprising:
- allocate one or more Demodulation Reference Signal (DMRS) REs corresponding to the one or more subcarrier frequencies,
 - wherein the one or more DMRS REs carry one or more respectively corresponding DMRS signals at a symbol having an index of 2 within the OFDM subframe and at the one or more subcarrier frequencies; and
 - wherein the PCRS signal is the same as the DMRS signal.
24. The machine readable storage media of either of claims 19 or 20, the operation comprising:
- allocate one or more additional PCRS REs to carry an additional PCRS signal for at least part of the one or more OFDM symbols at one or more additional subcarrier frequencies,
 - wherein the one or more PCRS correspond with a first antenna port; and
 - wherein the one or more additional PCRS correspond with a second antenna port.

110
120

Fig. 1

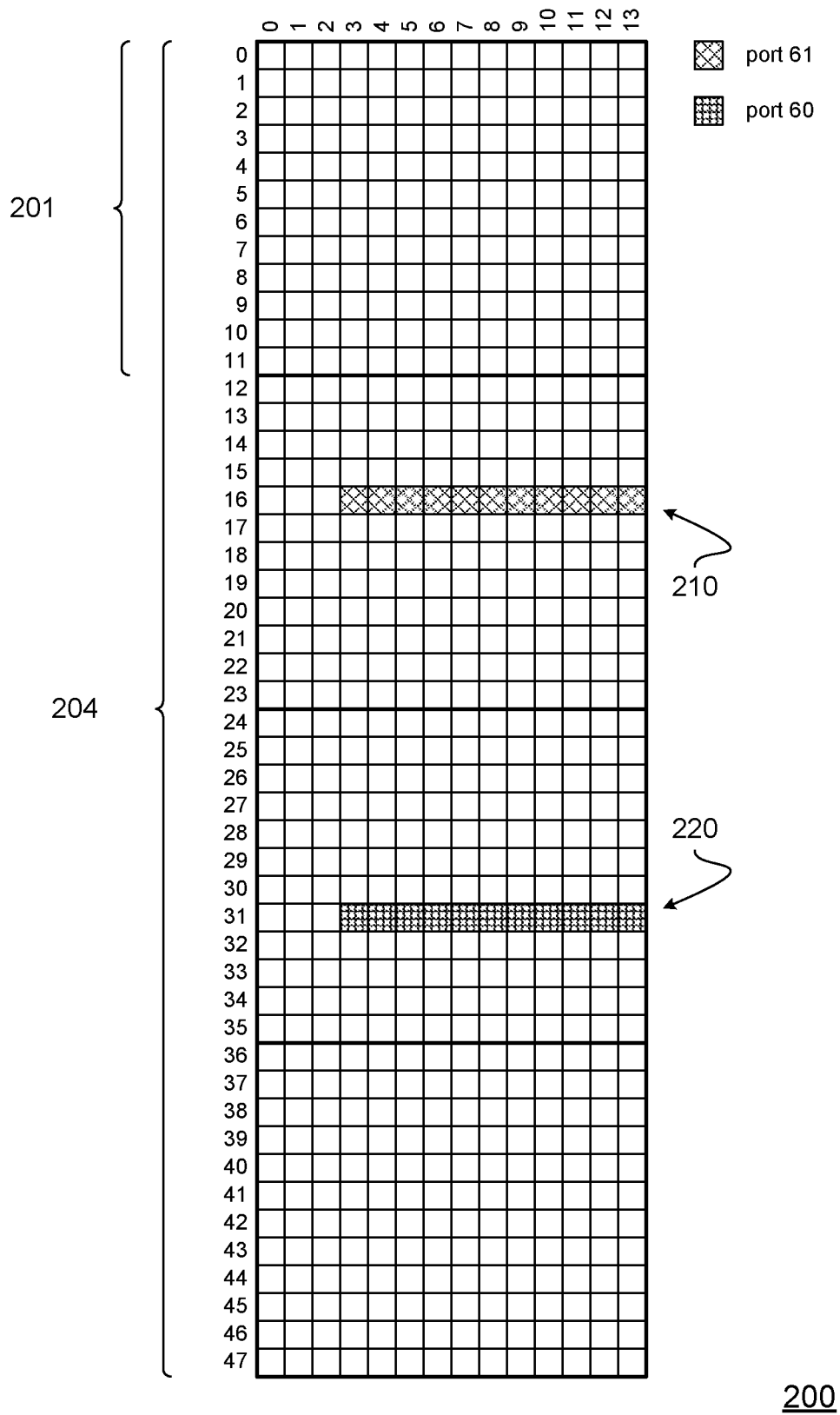


Fig. 2

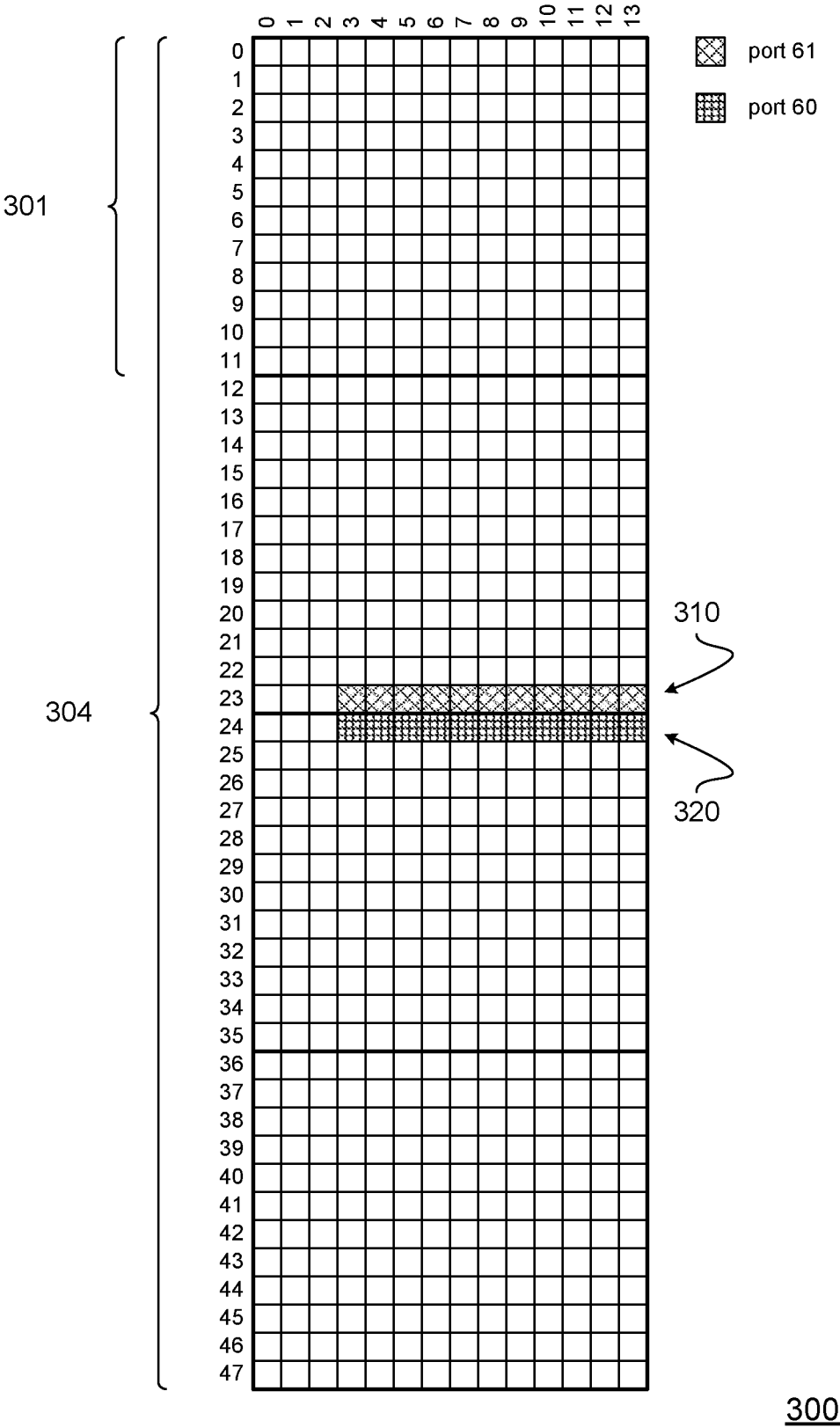


Fig. 3

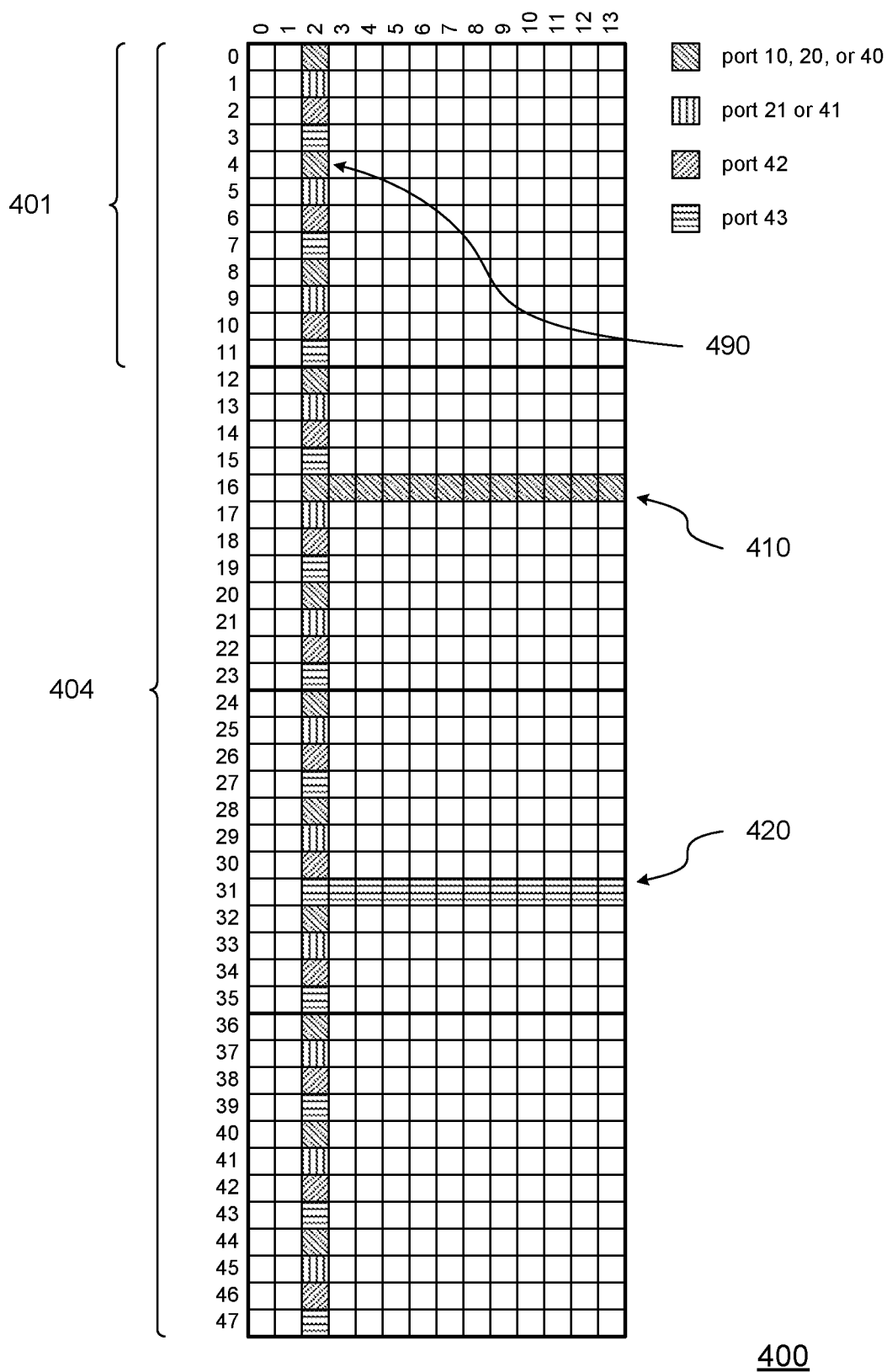
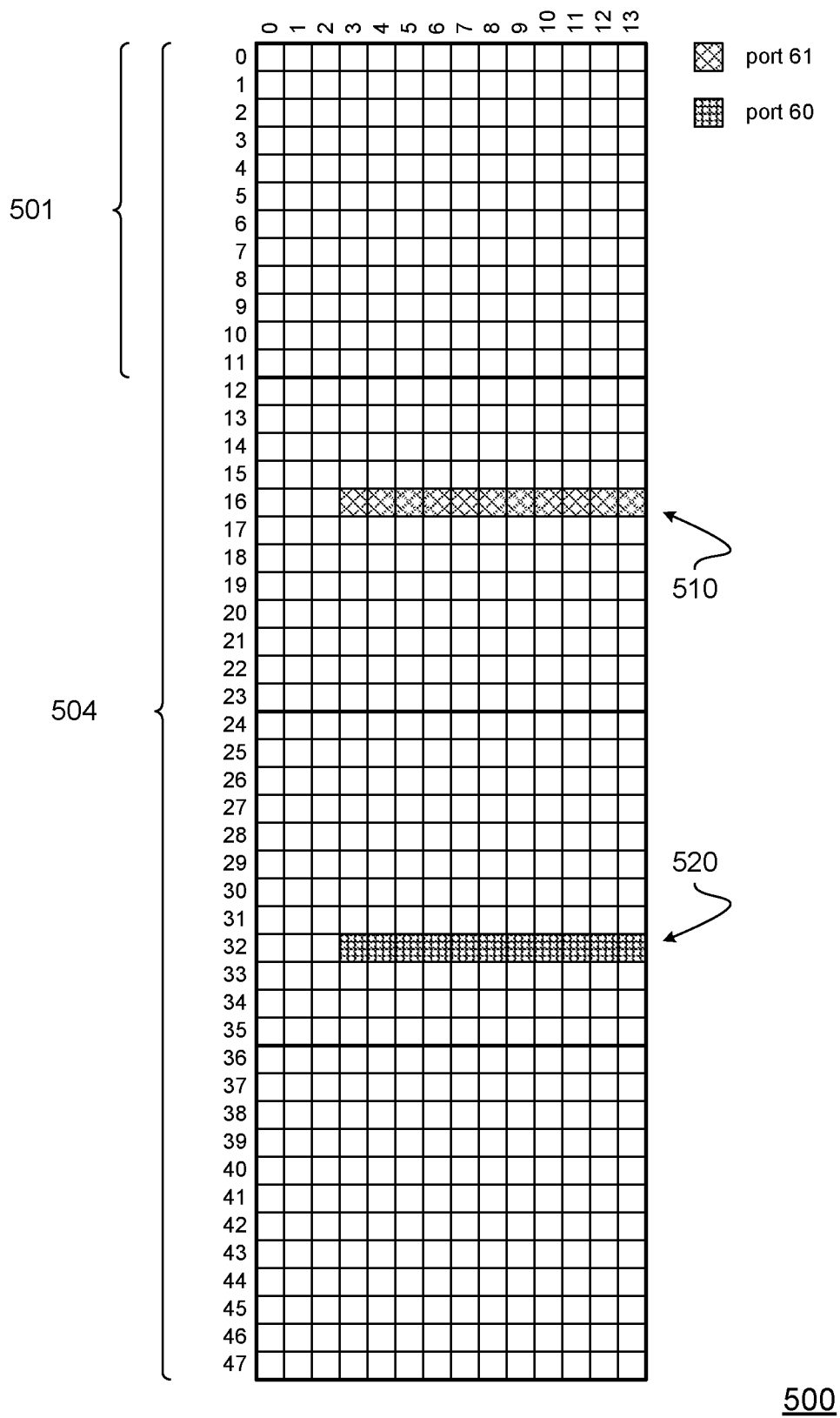


Fig. 4



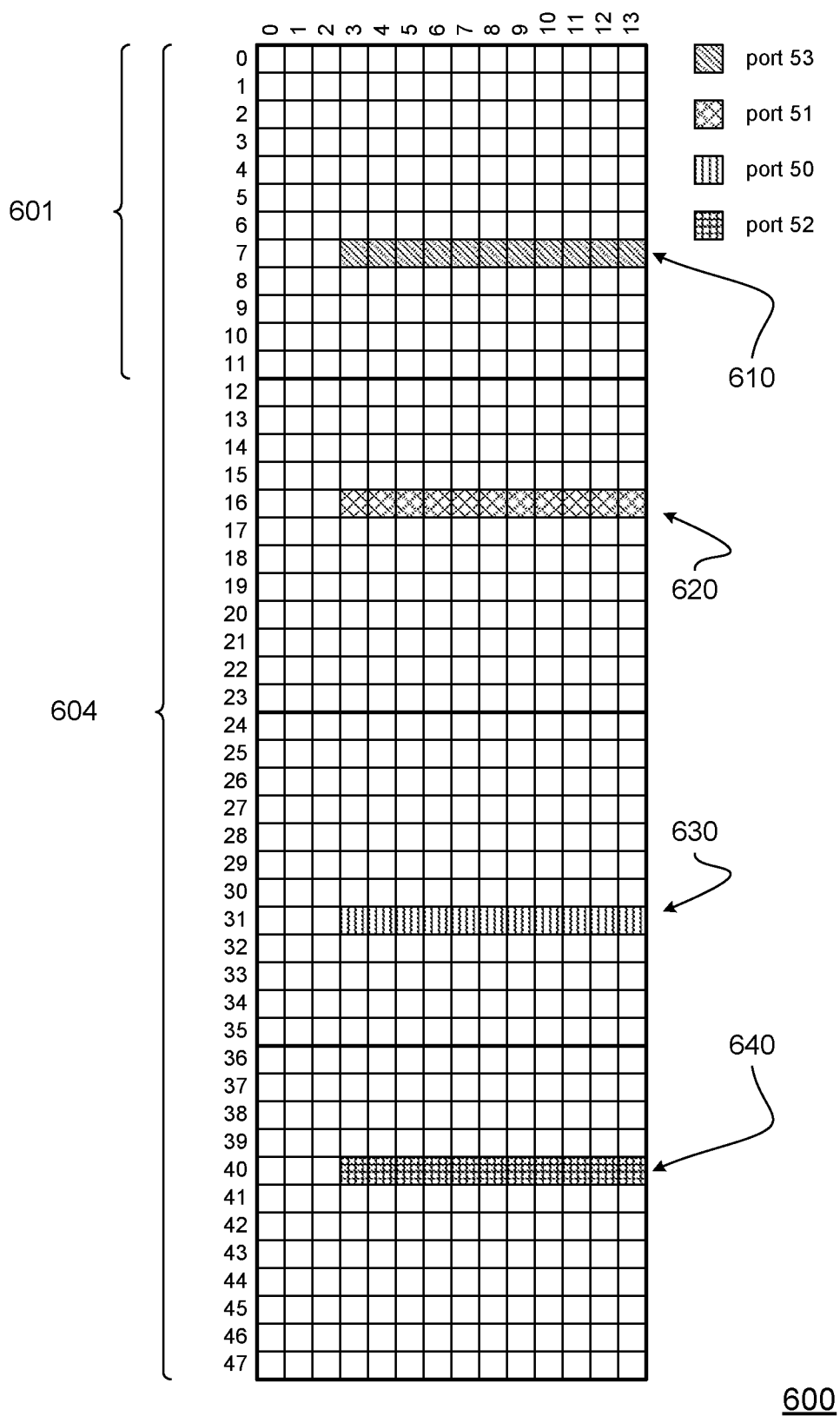


Fig. 6

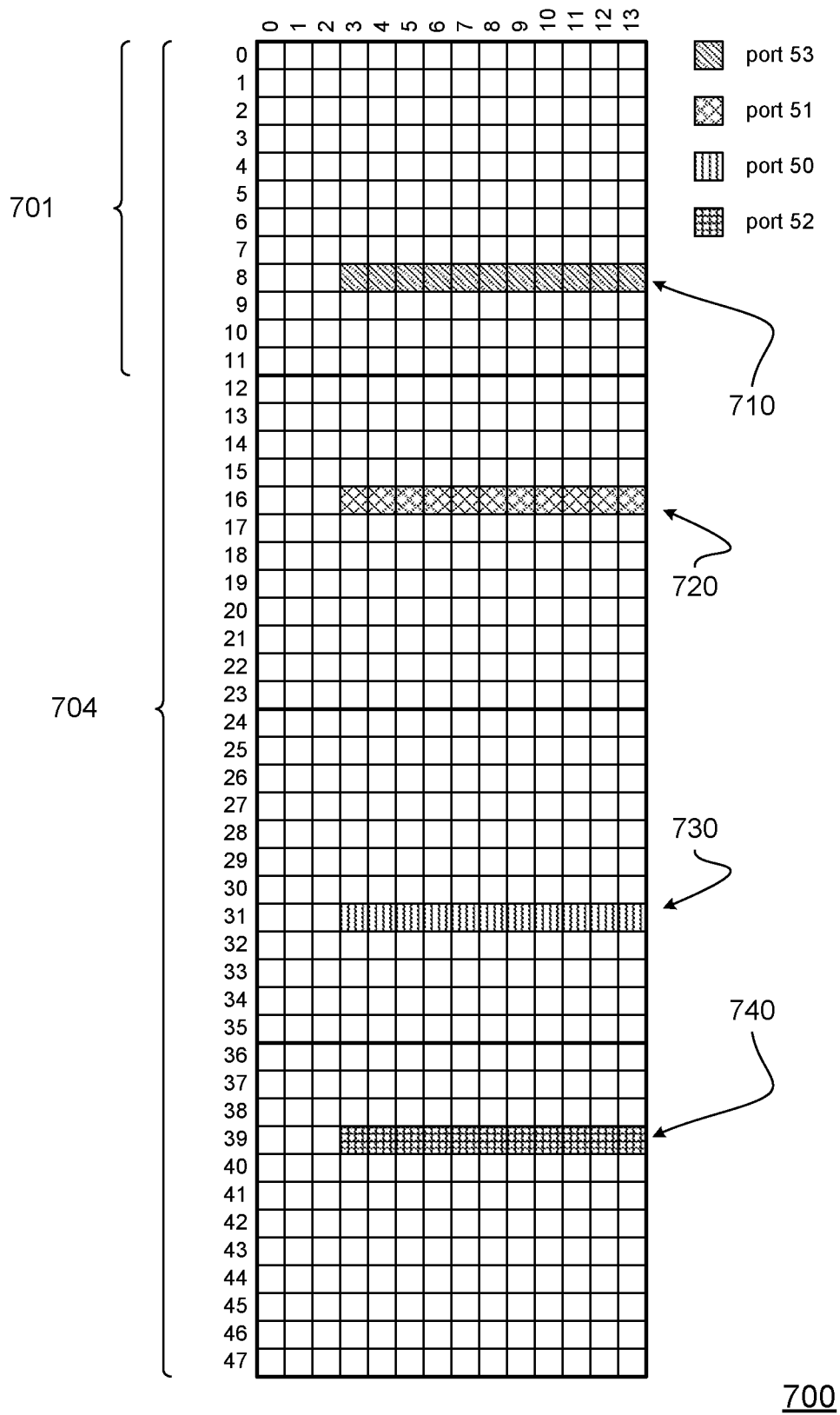


Fig. 7

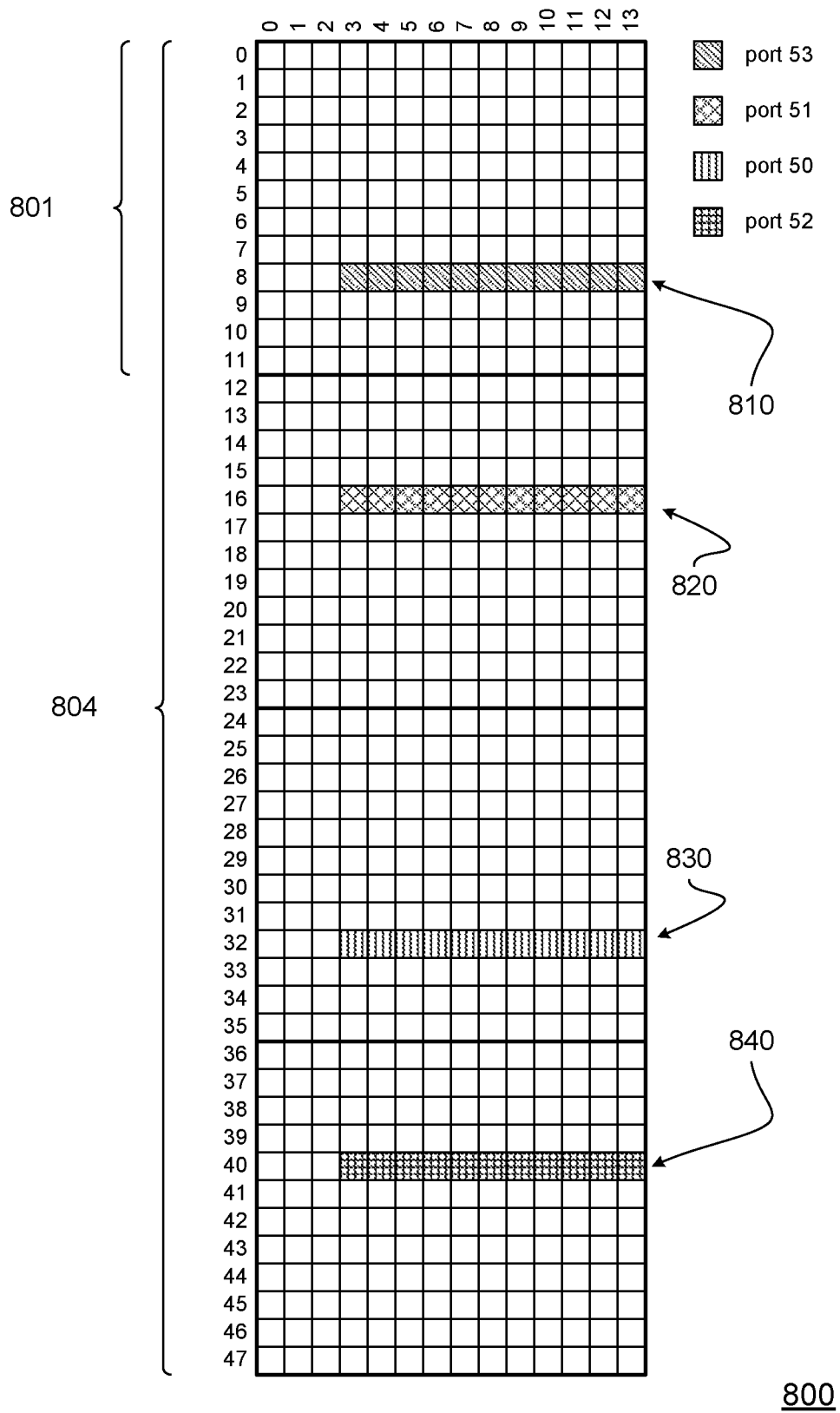
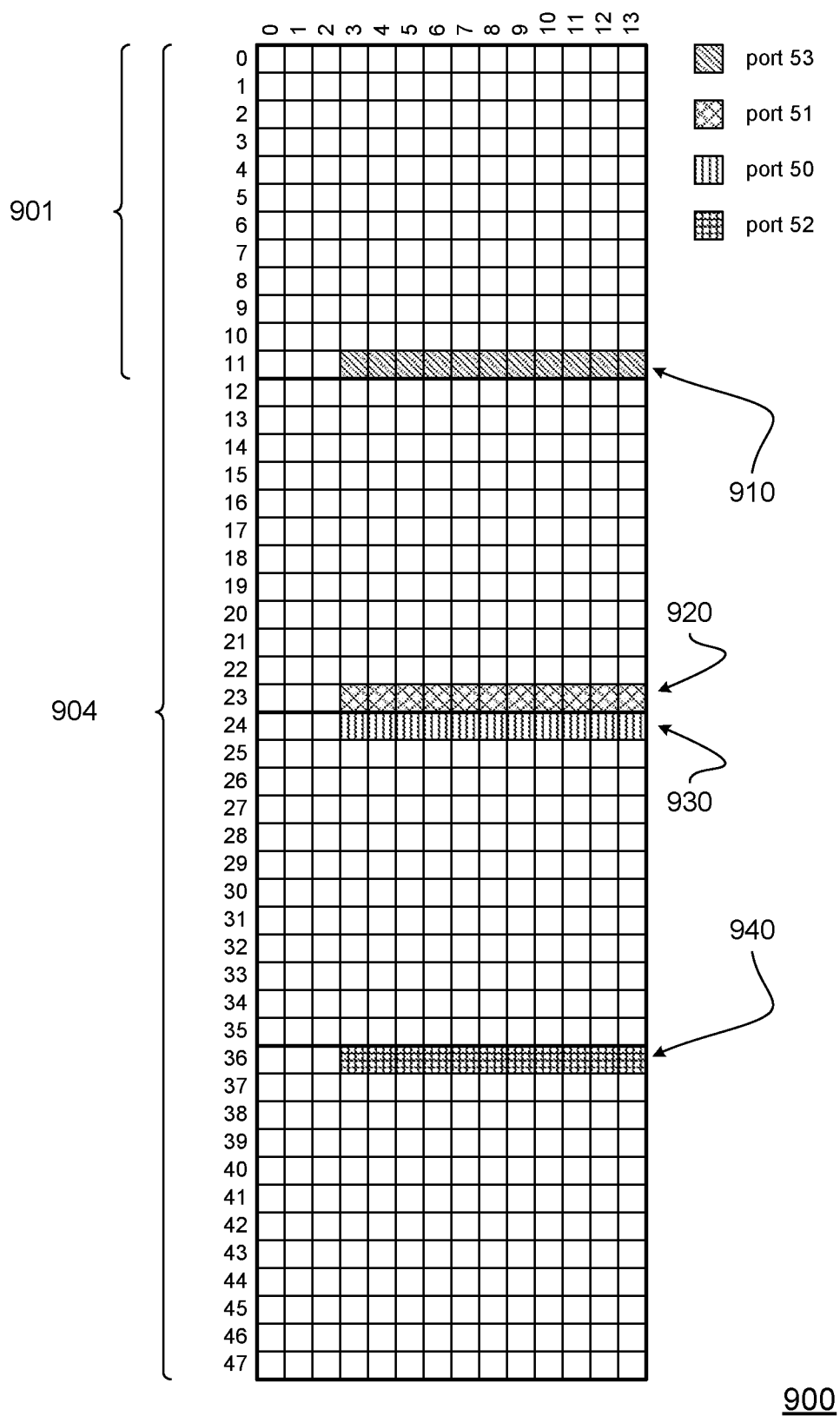


Fig. 8

**Fig. 9**

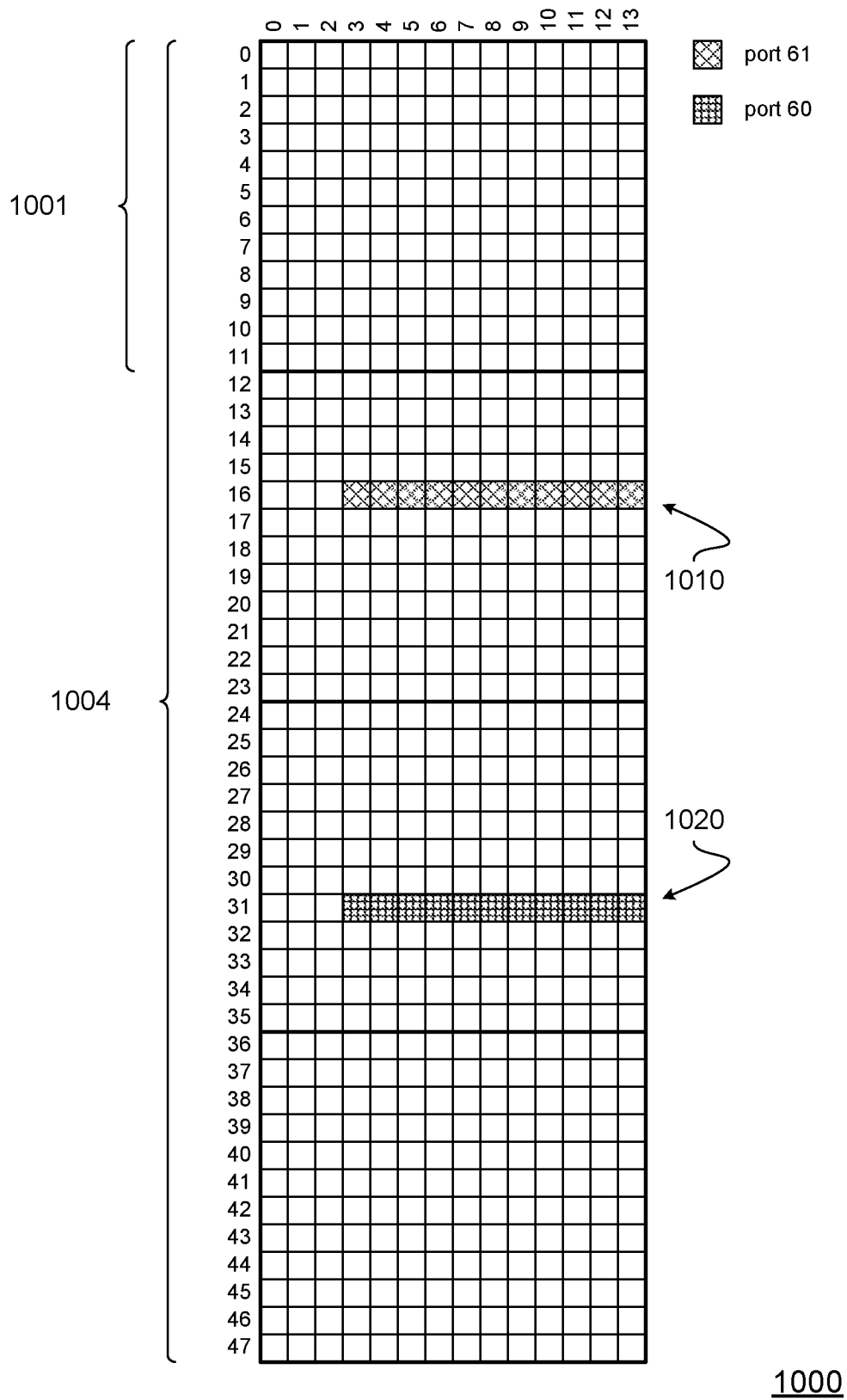


Fig. 10

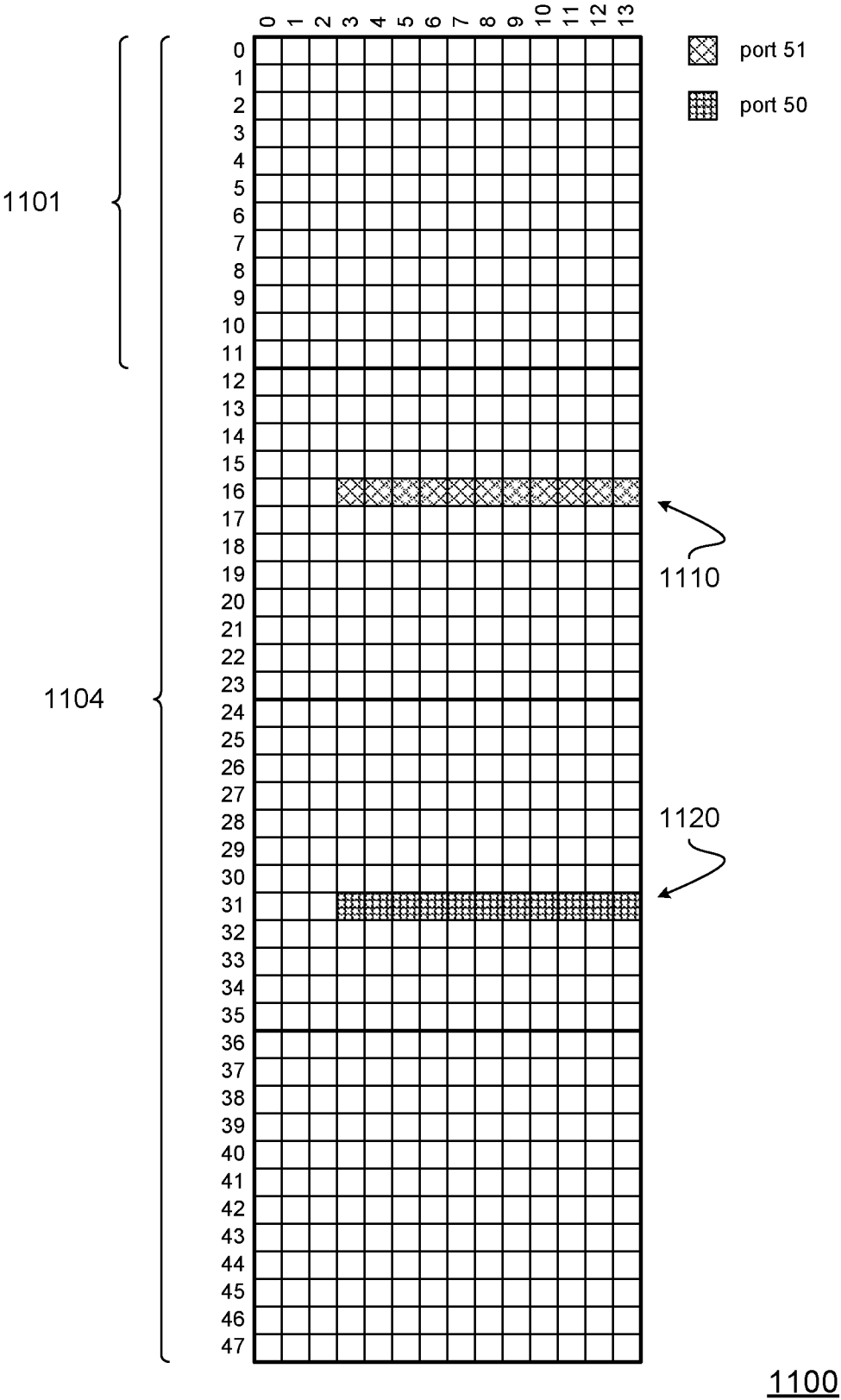


Fig. 11

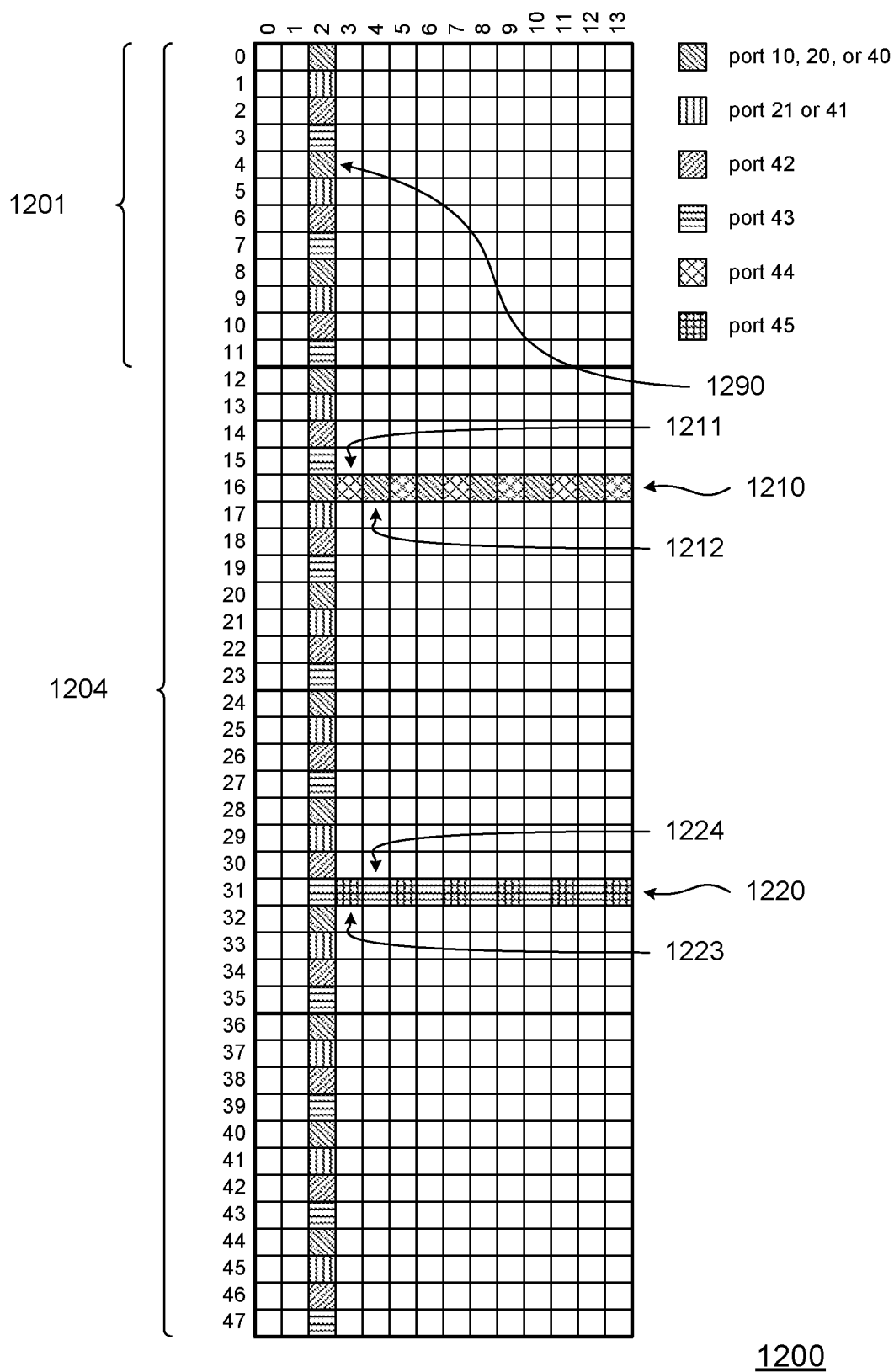
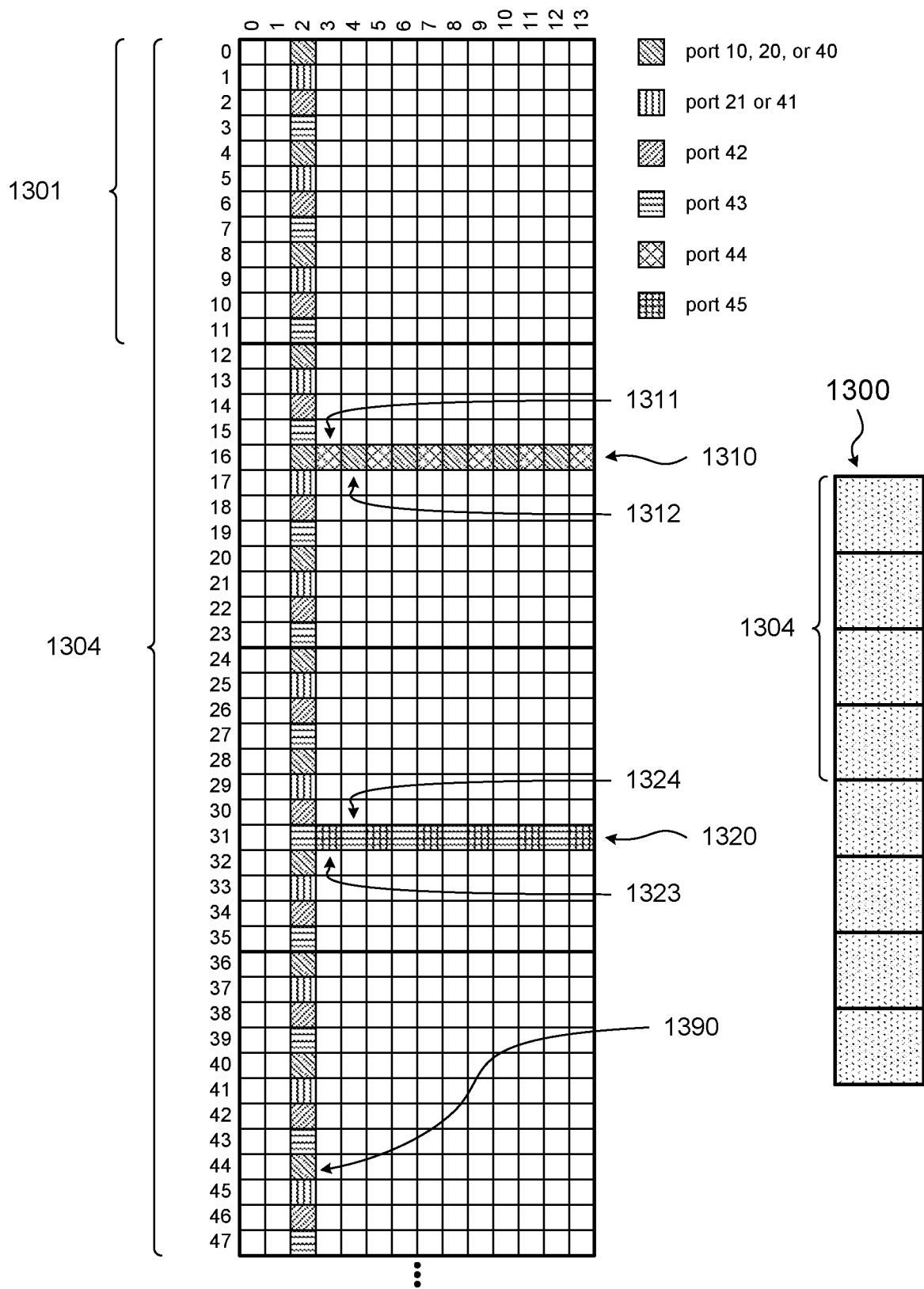
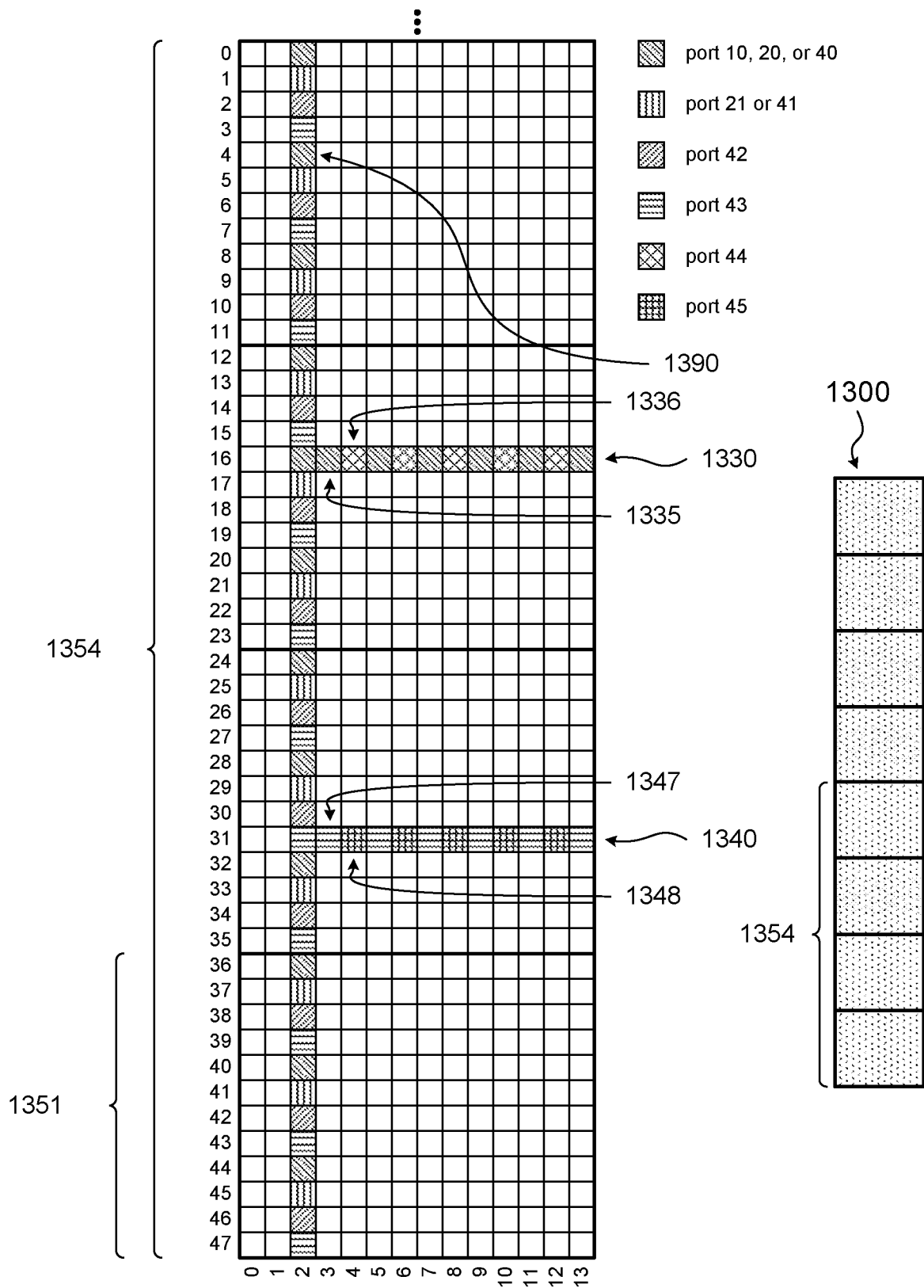


Fig. 12





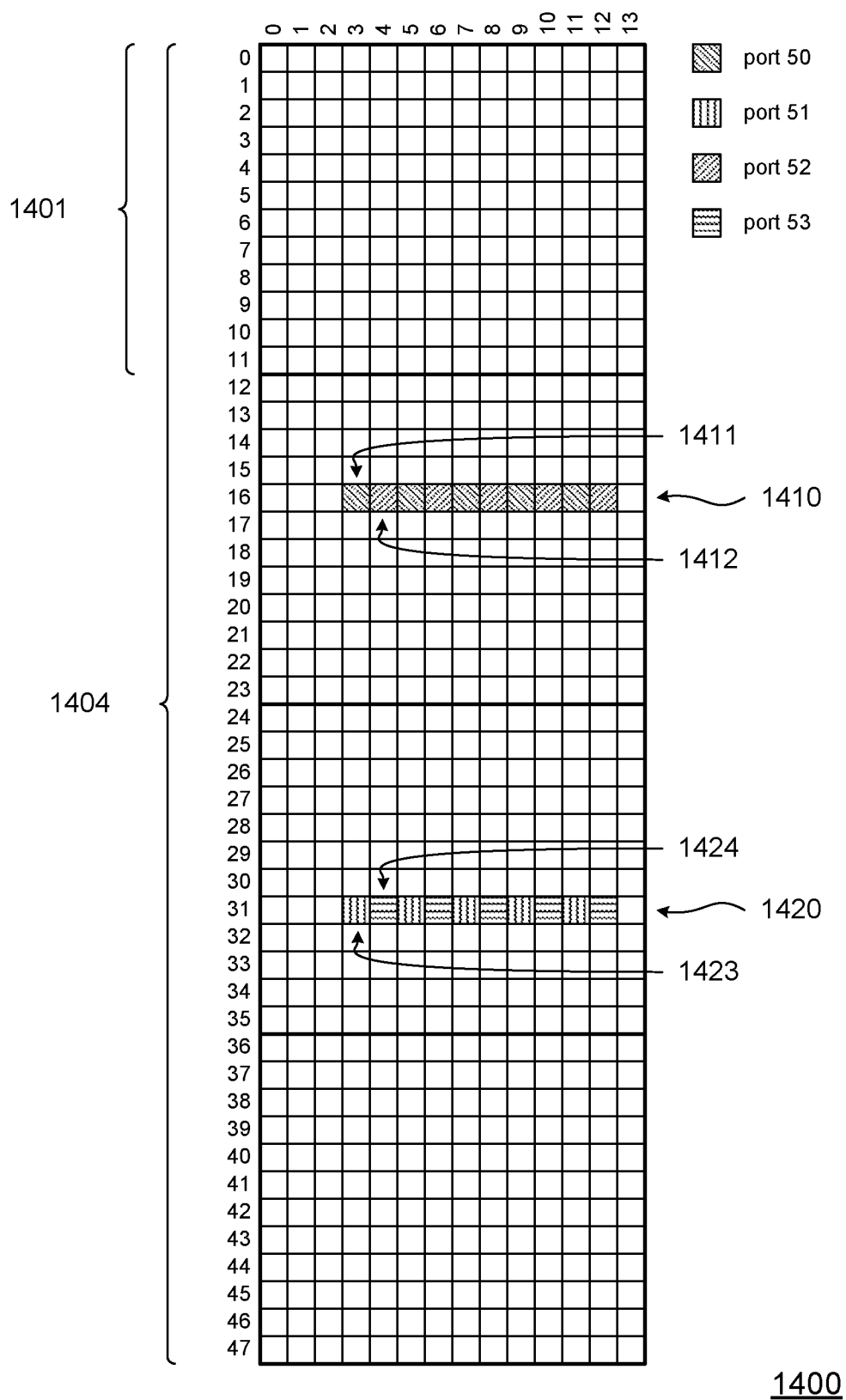


Fig. 14

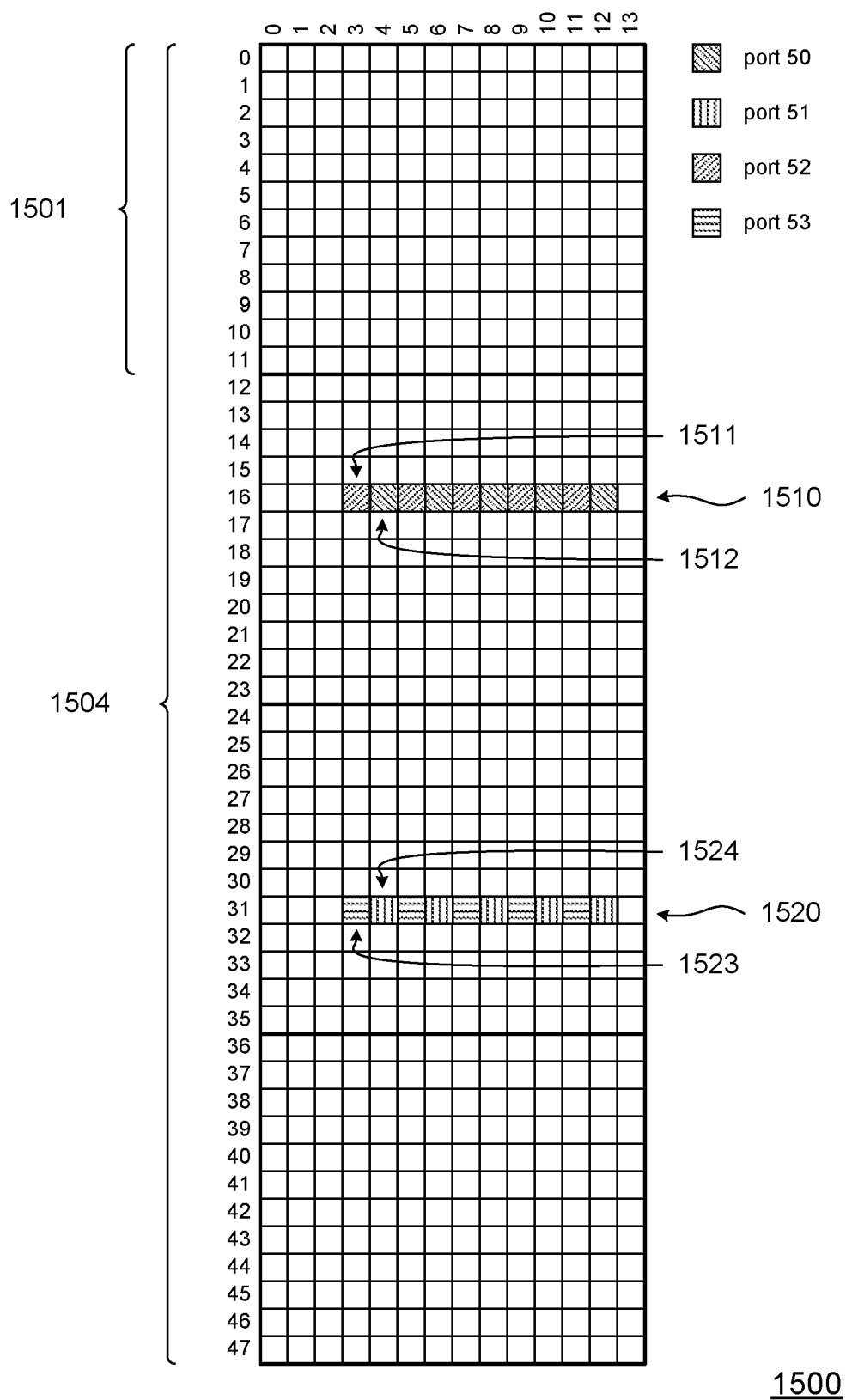
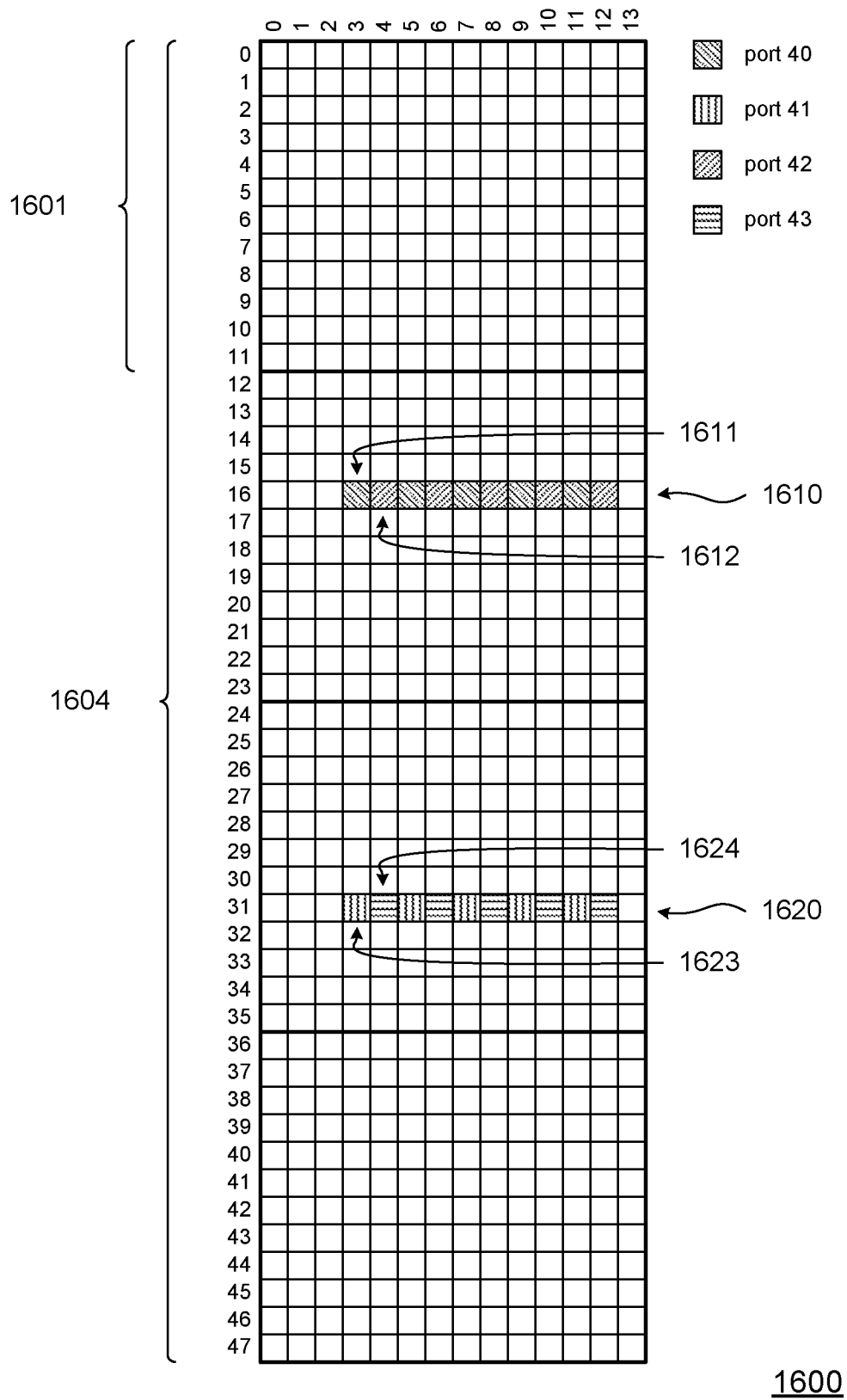


Fig. 15

**Fig. 16**

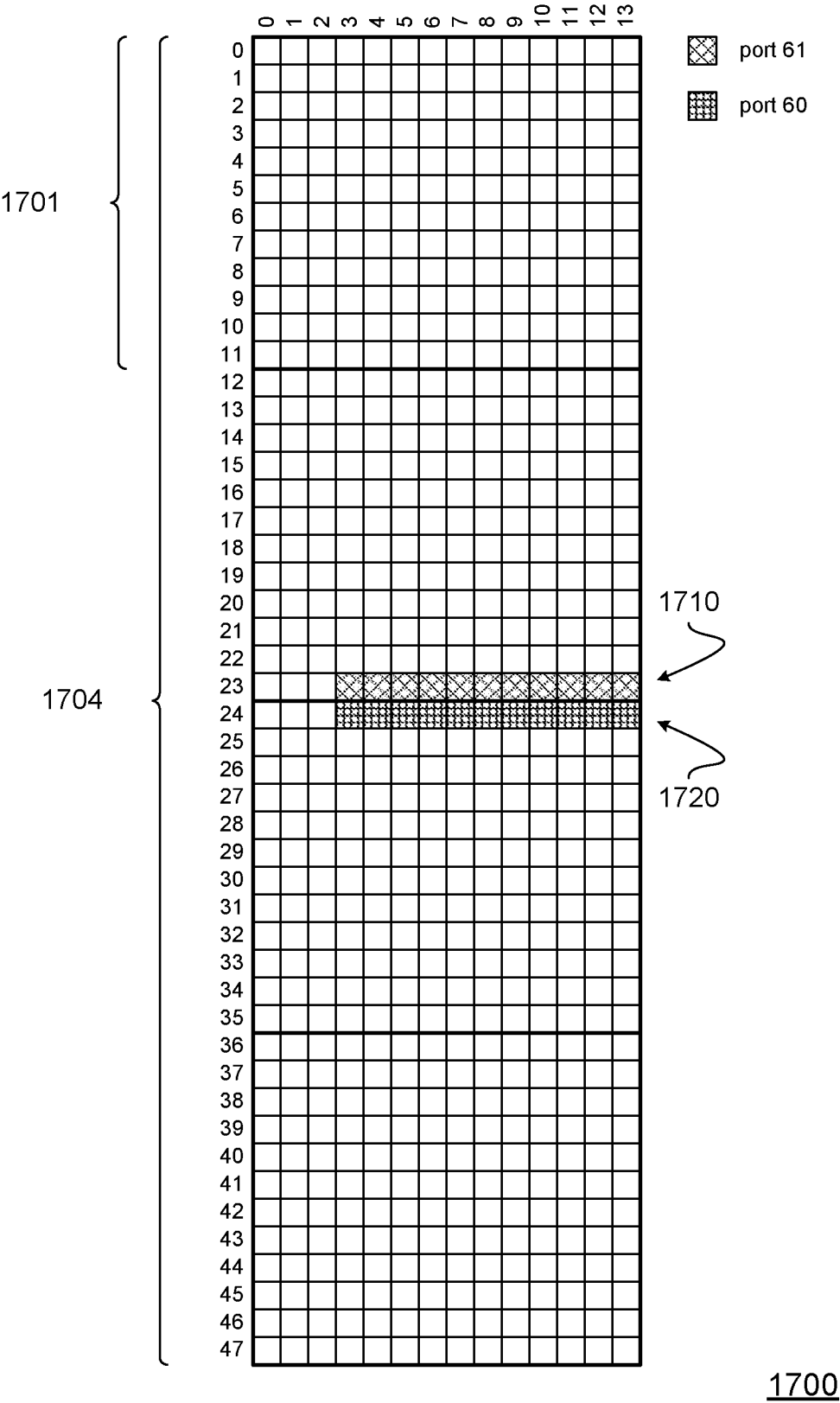


Fig. 17

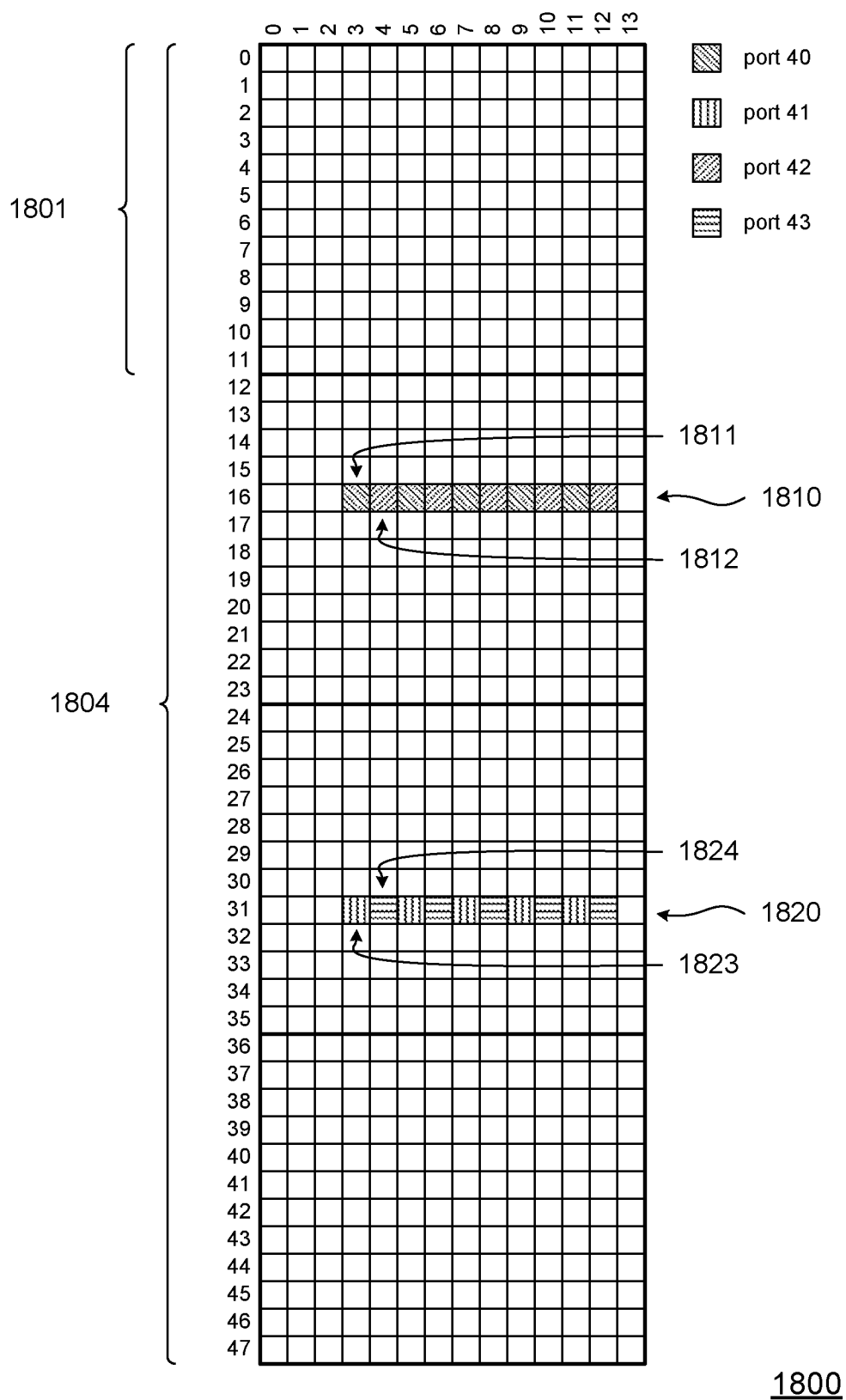


Fig. 18

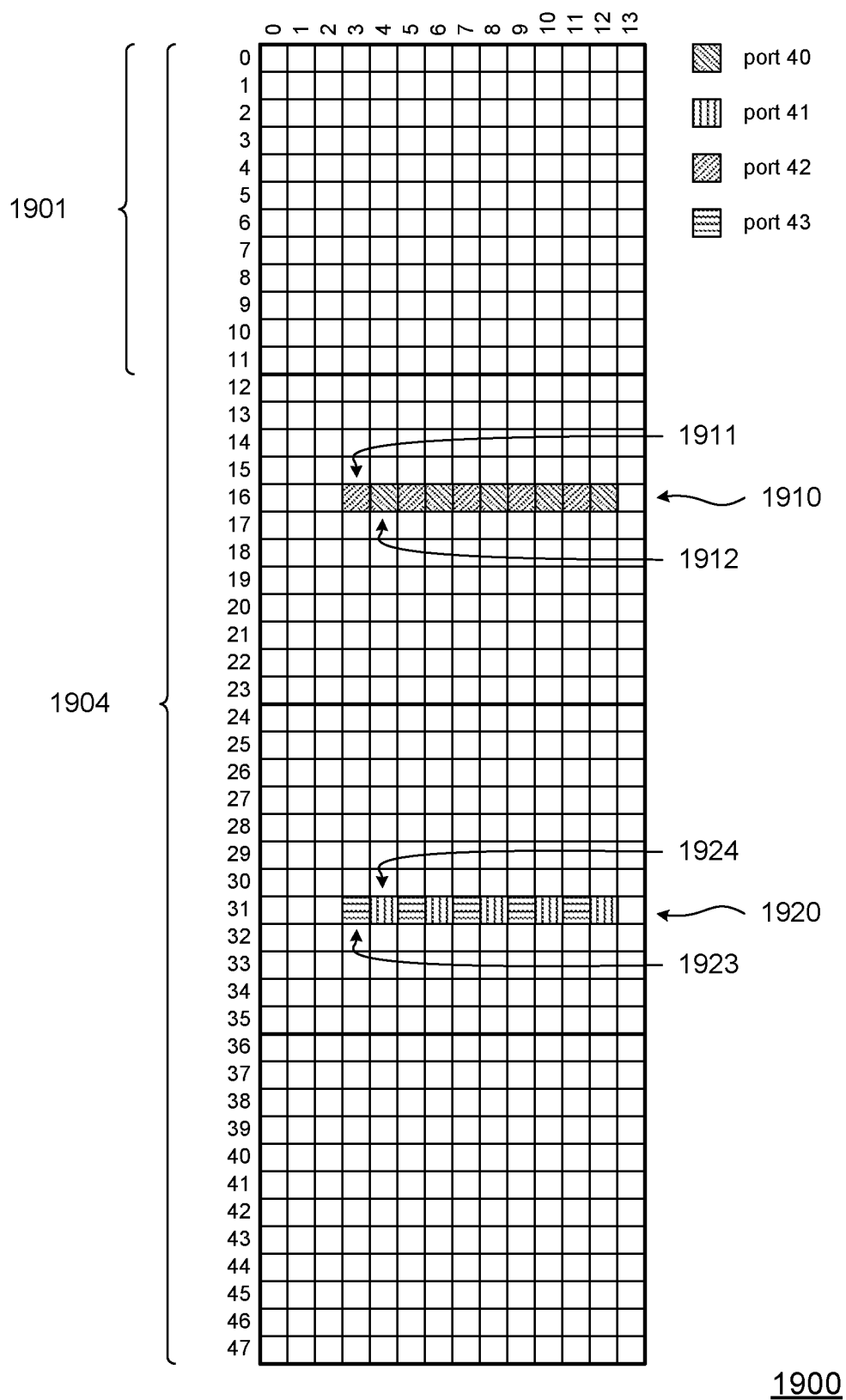


Fig. 19

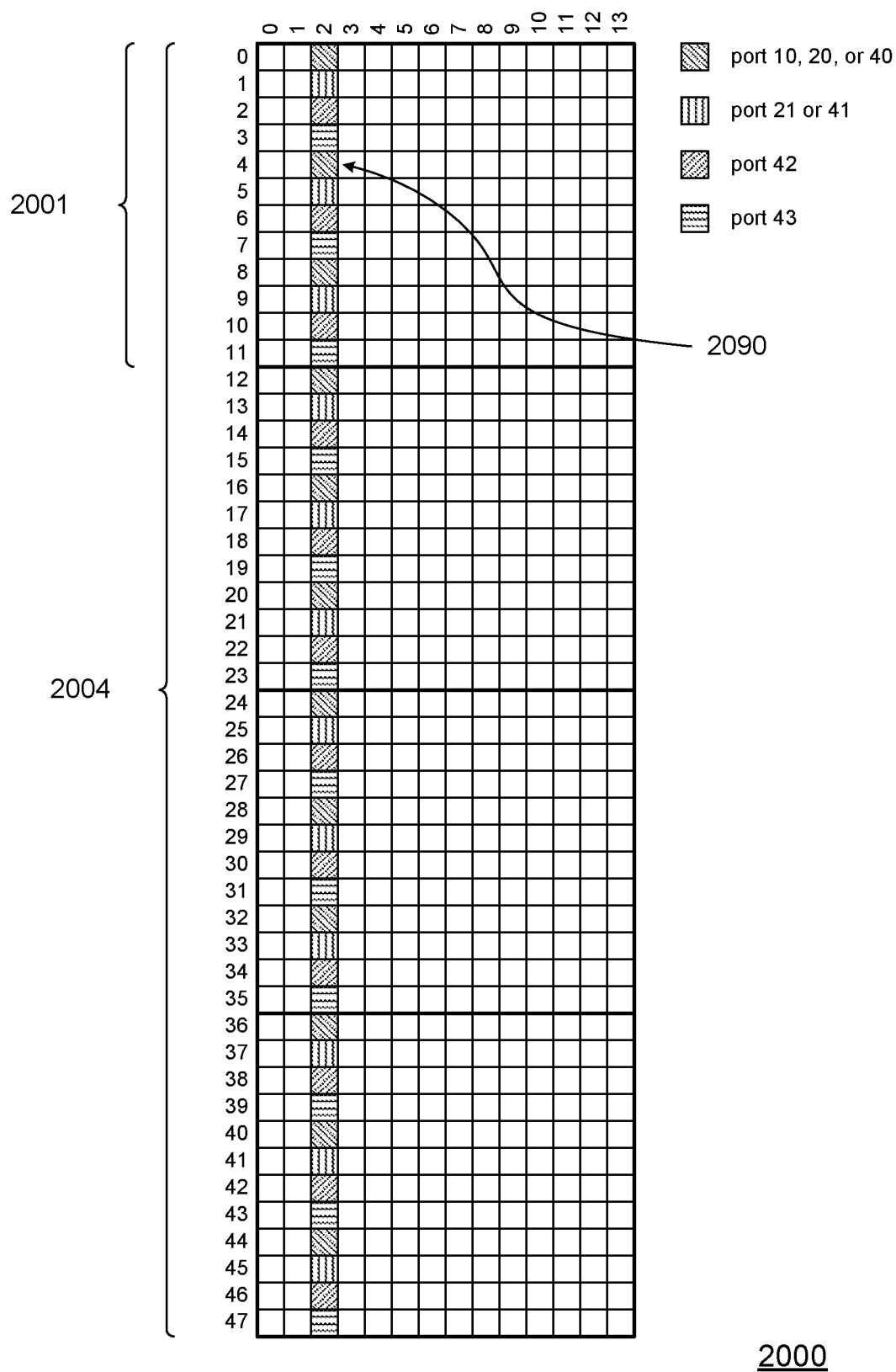


Fig. 20

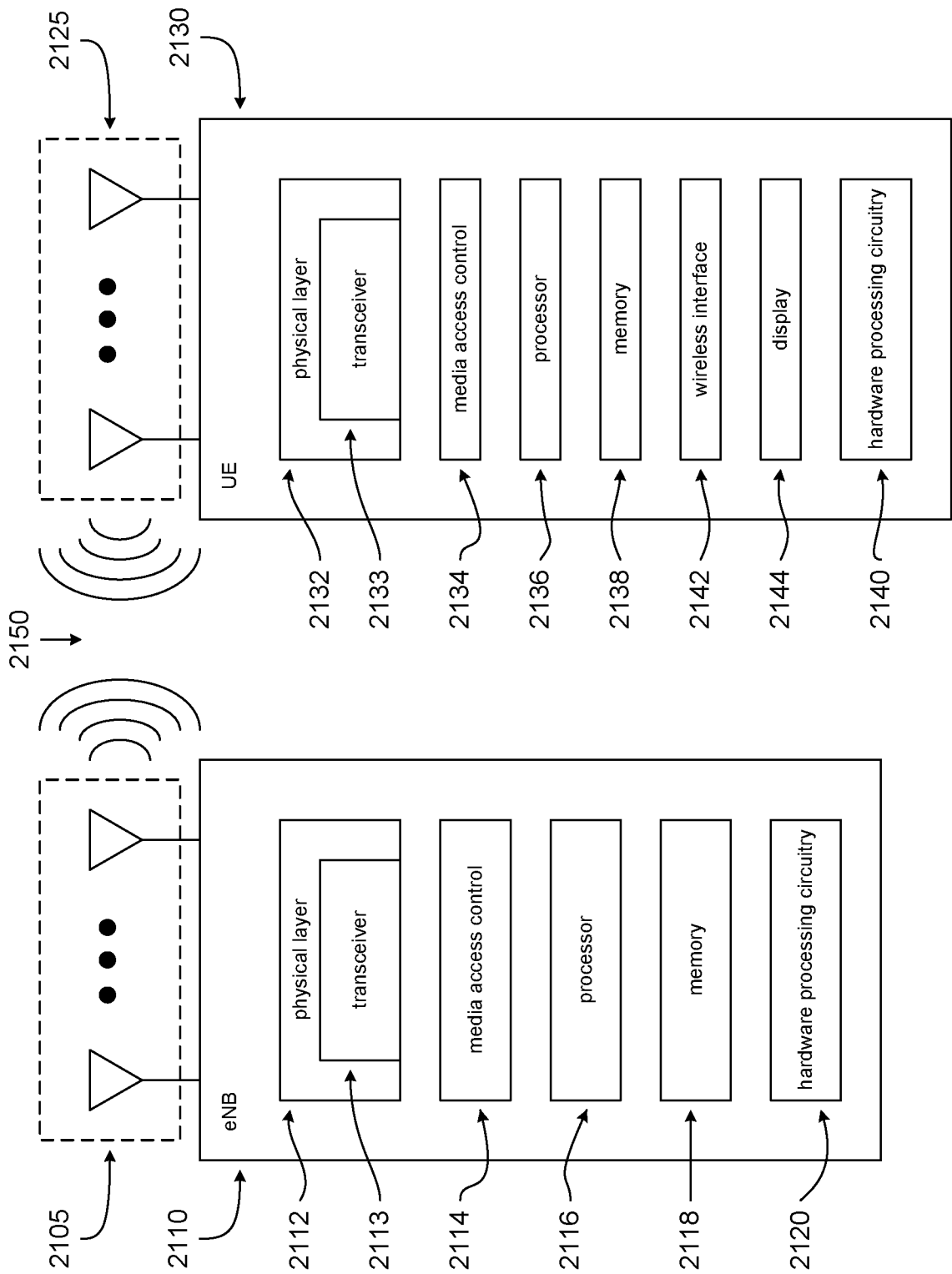


Fig. 21

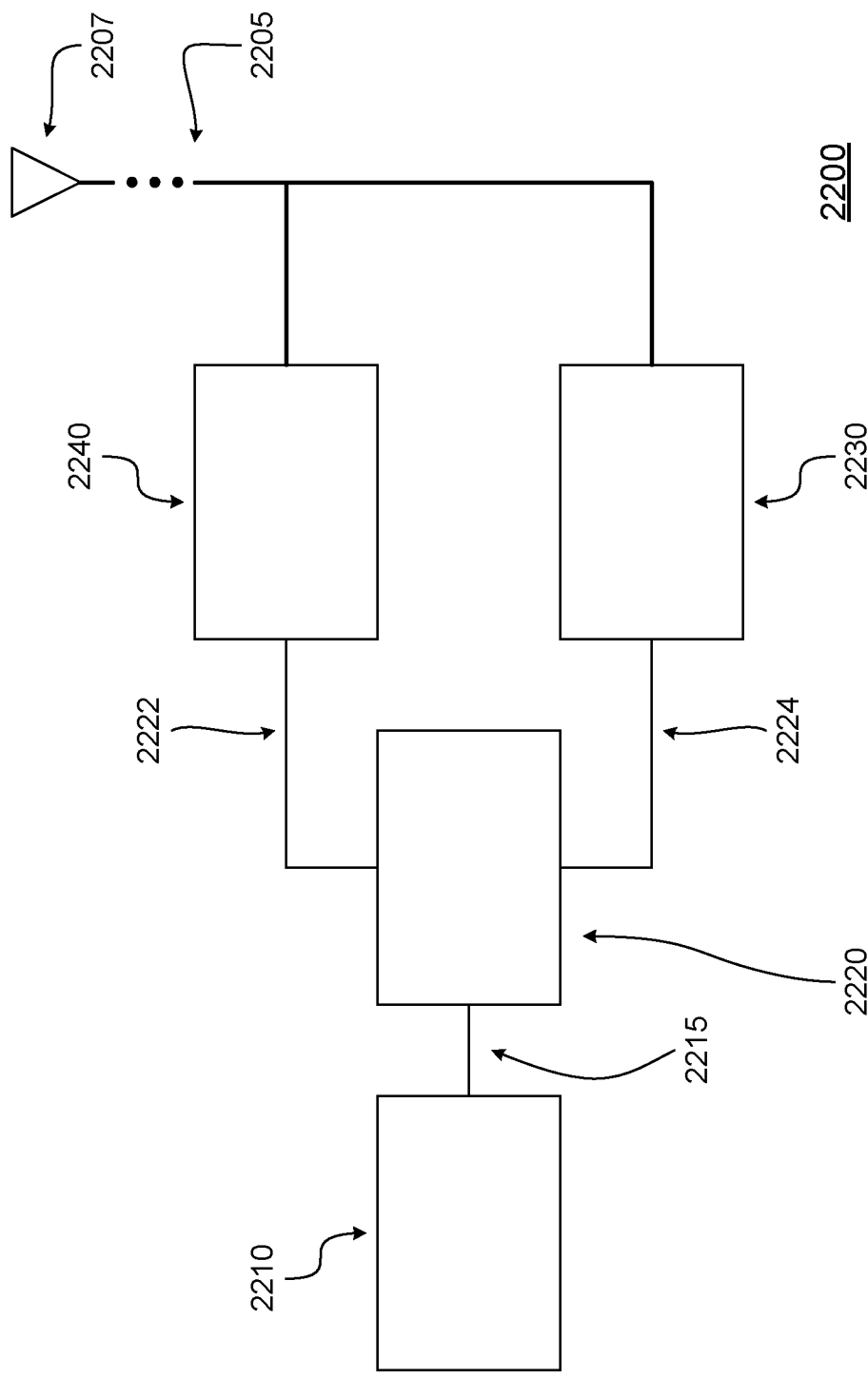


Fig. 22

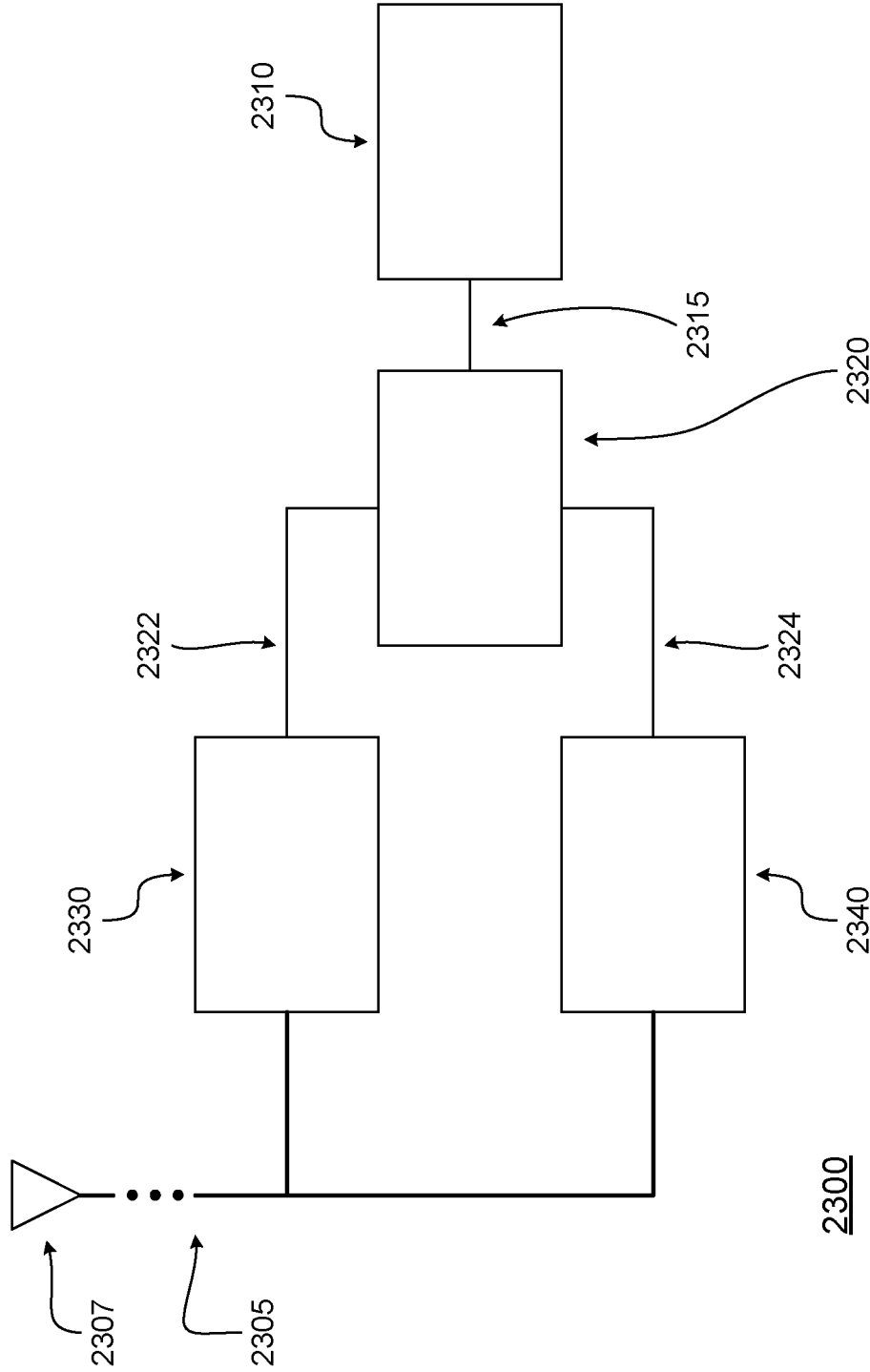
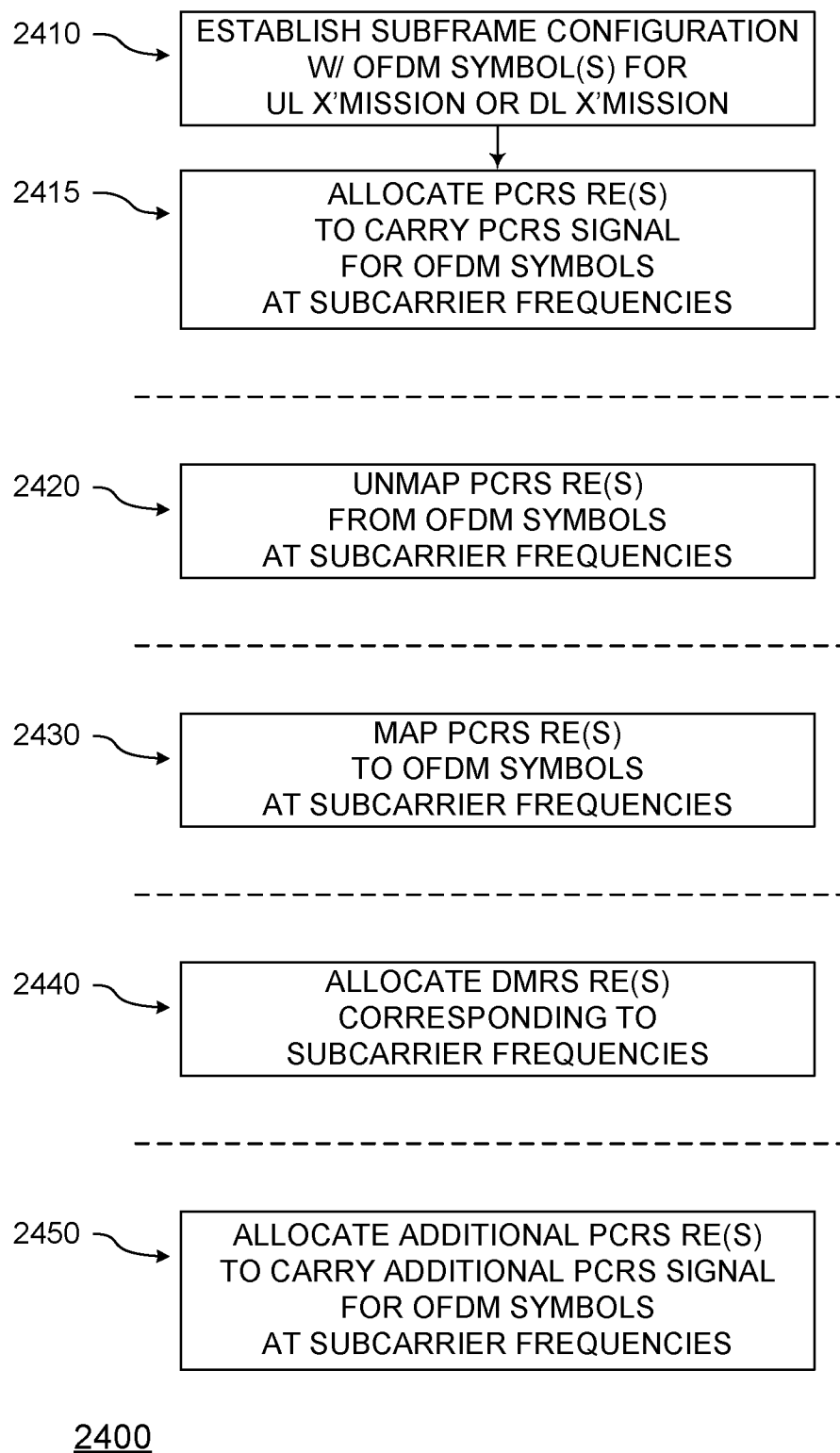
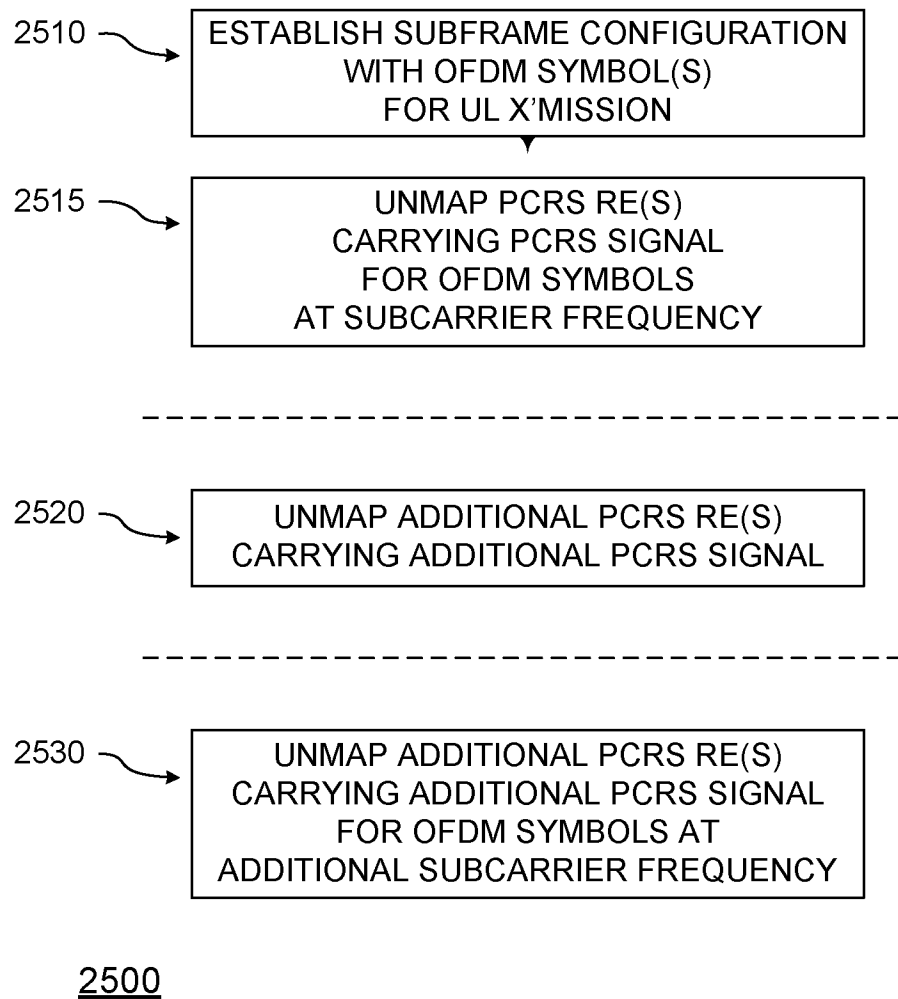
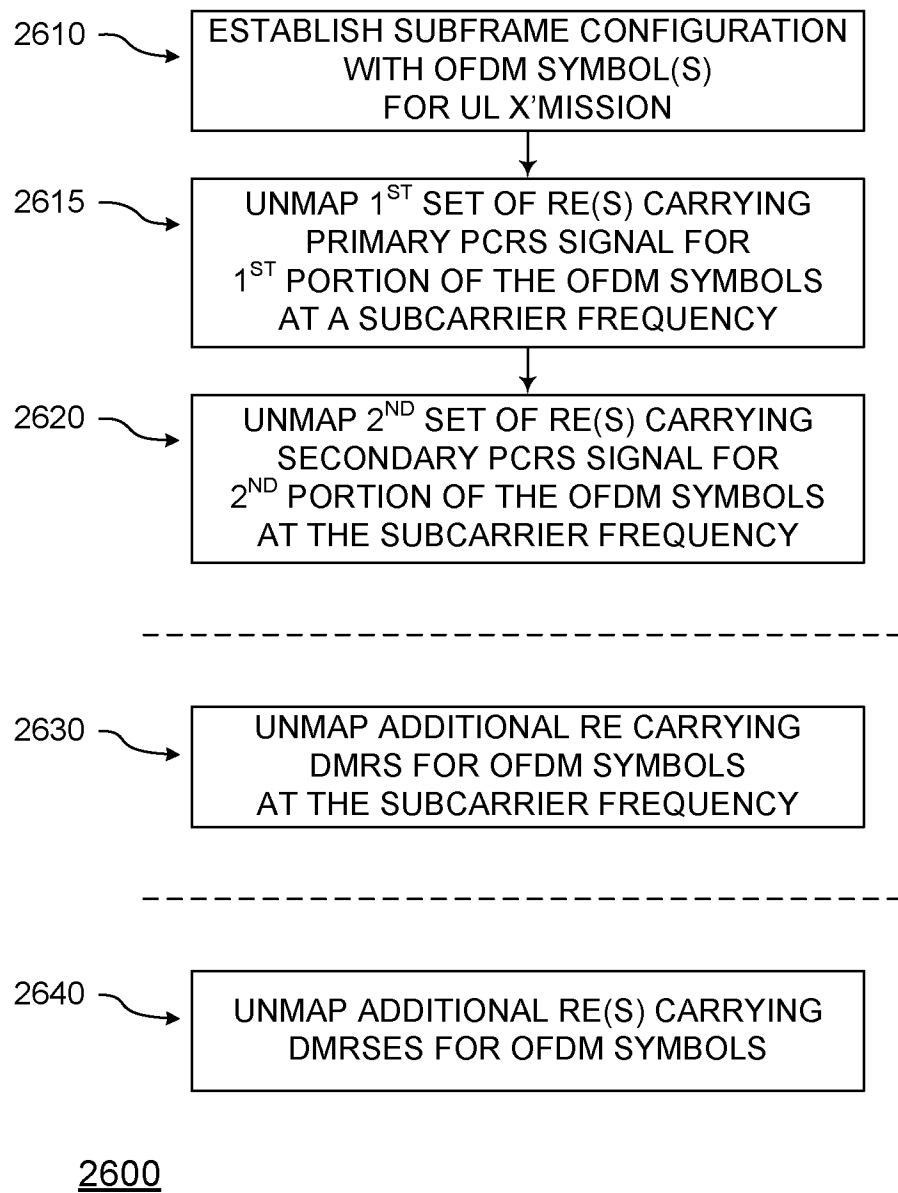
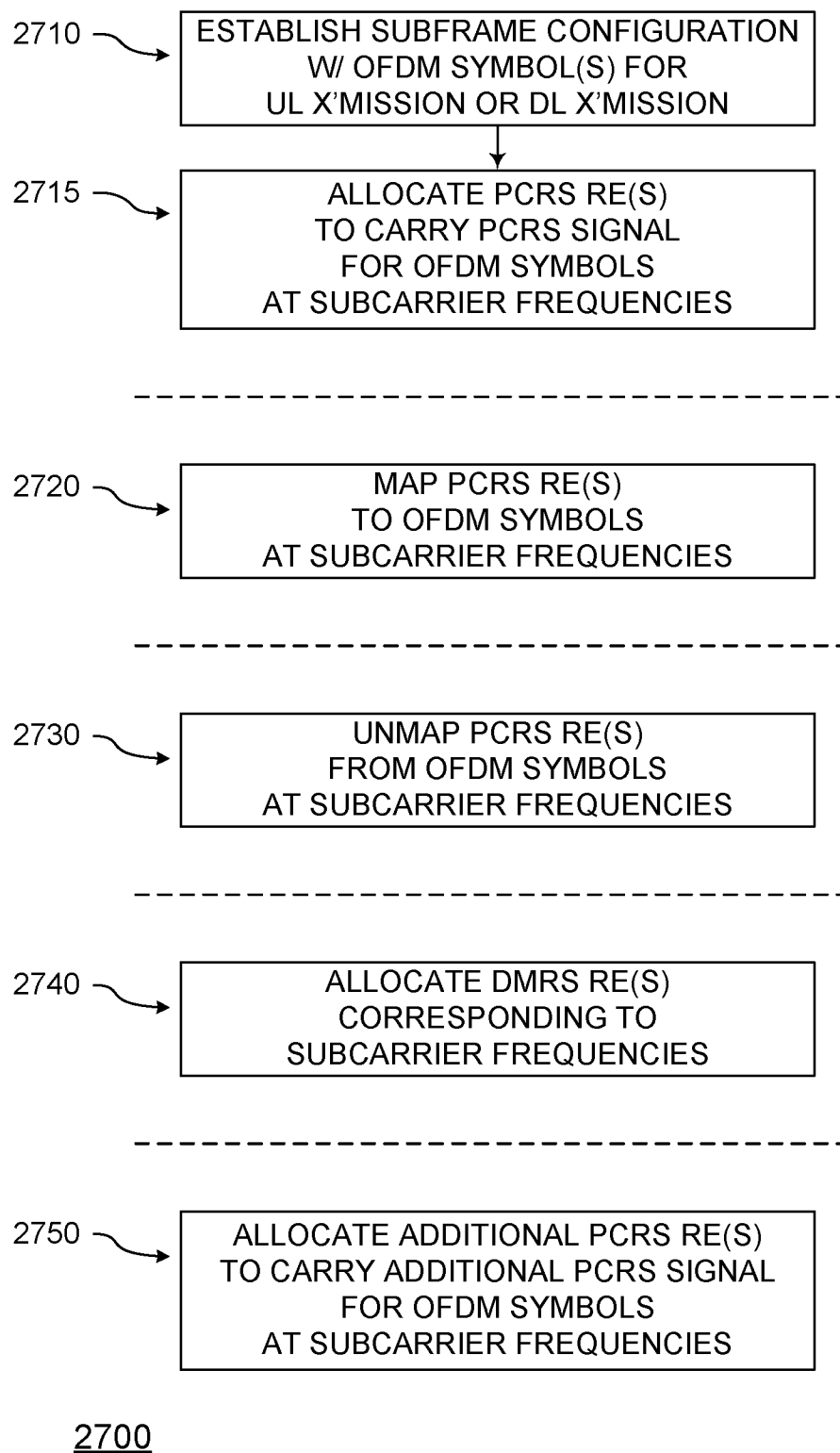


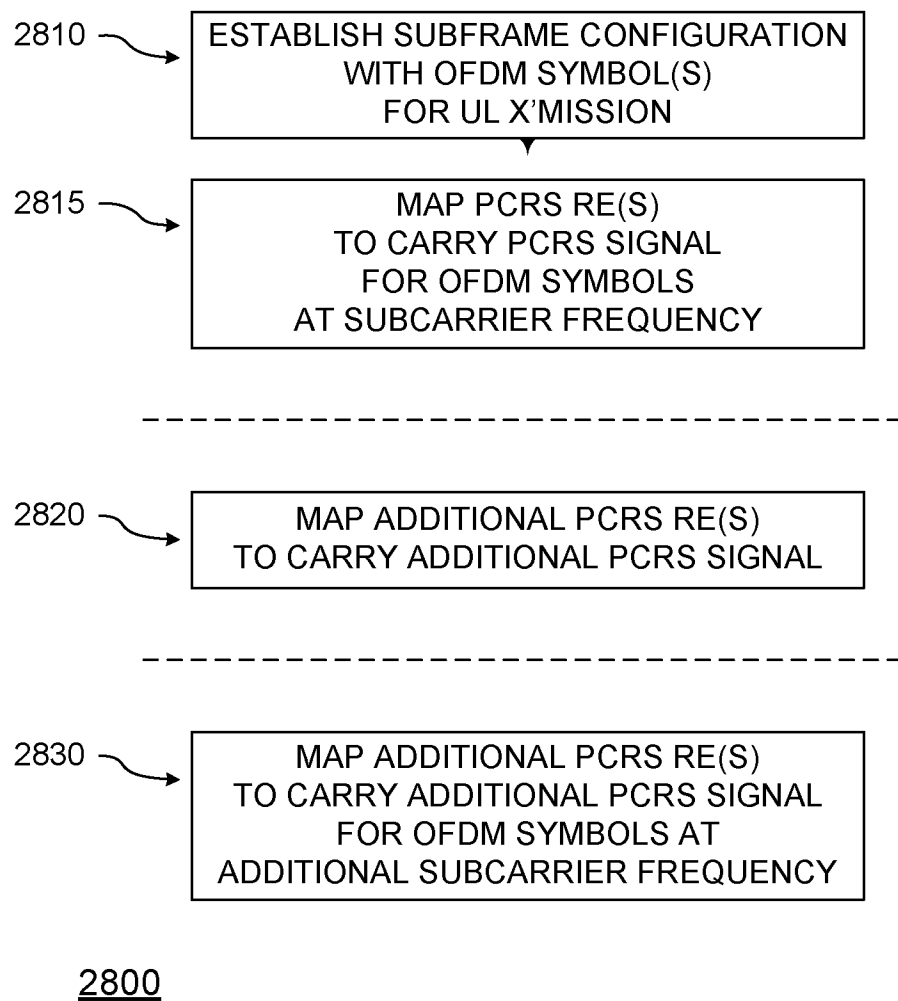
Fig. 23

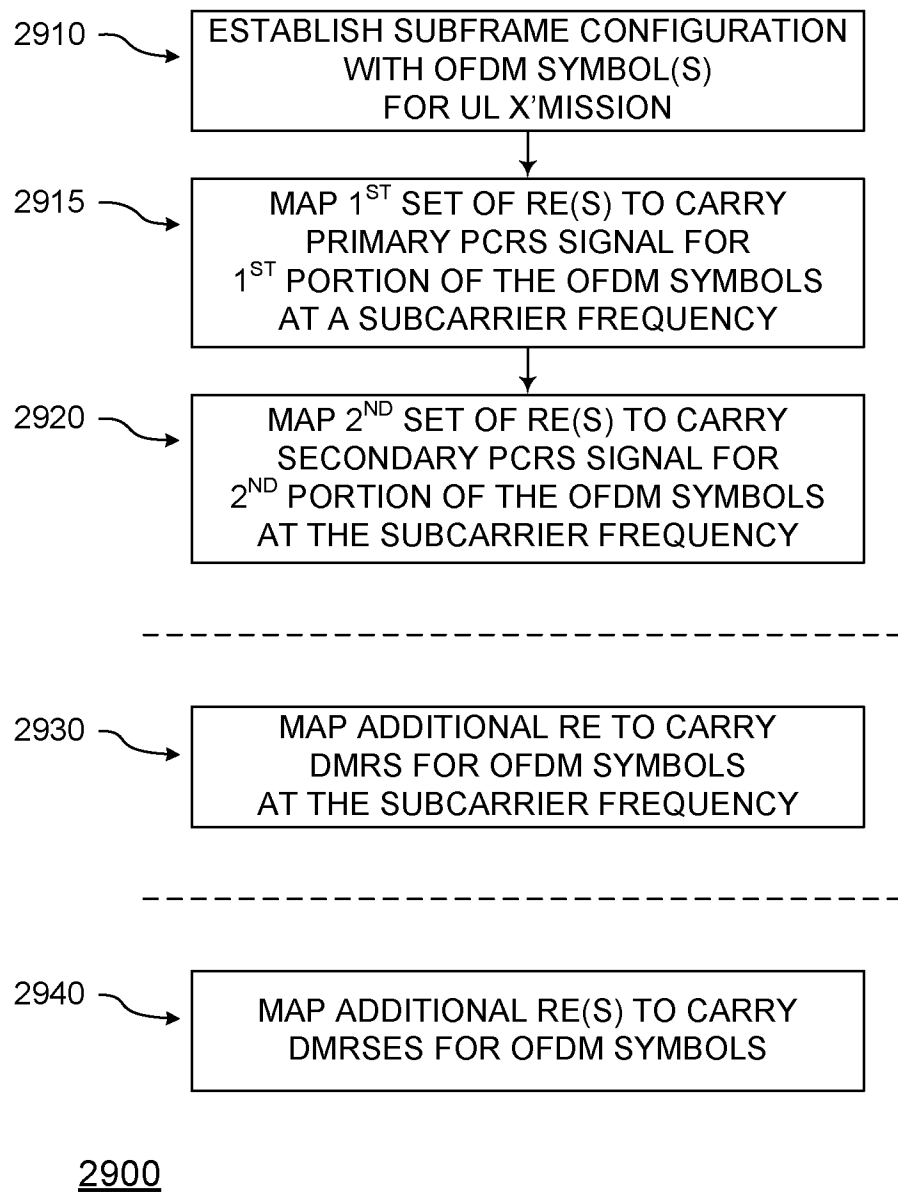
**Fig. 24**

**Fig. 25**

**Fig. 26**

**Fig. 27**

**Fig. 28**

**Fig. 29**

3000

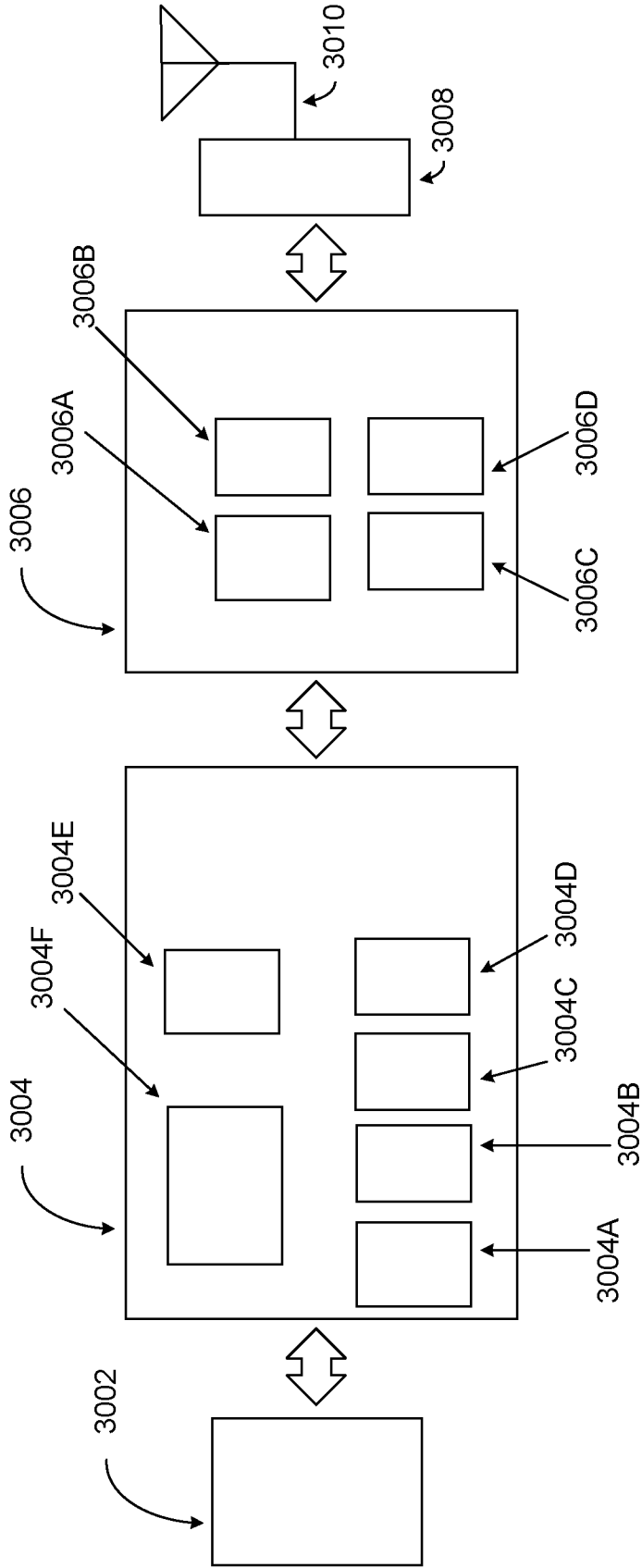


Fig. 30

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/031825

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L5/00
ADD.

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)
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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2016/000915 A1 (ERICSSON TELEFON AB L M [SE]) 7 January 2016 (2016-01-07) paragraph [0004] paragraph [0035] - paragraph [0040]; figure 1 paragraph [0046] paragraph [0058] paragraph [0077]; figure 6 paragraph [0081] - paragraph [0084]; figures 8-11 ----- -/--	1-24



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

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"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

1 August 2017

Date of mailing of the international search report

07/08/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Devillers, Bertrand

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/031825

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	HUAWEI ET AL: "DMRS enhancement for V2V", 3GPP DRAFT; R1-156908, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Anaheim, USA; 20151115 - 20151122 15 November 2015 (2015-11-15), XP051003257, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/RAN1/Docs/ [retrieved on 2015-11-15] figure 2	5,11,17, 23
A	----- ITRI: "Considerations of DMRS Enhancement in the High Doppler Case for PC5- based V2V", 3GPP DRAFT; R1-157088, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Anaheim, USA; 20151115 - 20151122 15 November 2015 (2015-11-15), XP051003379, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/RAN1/Docs/ [retrieved on 2015-11-15] figure 5	5,11,17, 23
A	----- NTT DOCOMO ET AL: "Initial views on numerology for NR access technology", 3GPP DRAFT; R1-163113, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Busan, Korea; 20160411 - 20160415 1 April 2016 (2016-04-01), XP051079875, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_84b/Docs/ [retrieved on 2016-04-01] Section 3.2 -----	1-24

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/031825

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2016000915 A1	07-01-2016	CN 106664278 A	10-05-2017
		EP 3161979 A1	03-05-2017
		WO 2016000915 A1	07-01-2016
