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- (54) Title: BEAMFORMING DEVICE FOR FORMING DIFFERENT BEAMS FOR CONTROL AND DATA SIGNAL

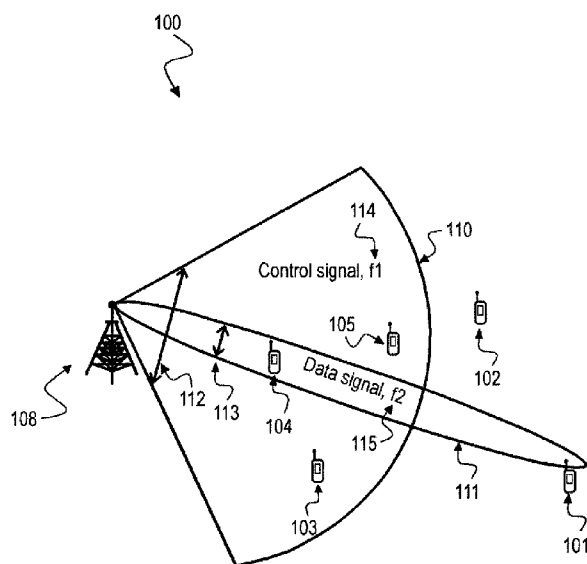


Fig. 1

- (57) Abstract: P95627PCT43 ABSTRACT OF THE DISCLOSURE The disclosure relates to a beamforming device (300), comprising: a baseband circuit (301) configured to provide a control signal (310) and a data signal (311); and a transceiver circuit (302) configured to: convert the control signal (310) to a first frequency (f1) of a first radio carrier (314), form a first transmission beam (110) having a first beam width (112) based on the converted control signal (310), convert the data signal (311) to a second frequency (f2) of a second radio carrier (315), and form a second transmission beam (111) having a second beam width (113) based on the converted data signal (311), wherein the first frequency (f1) is lower than the second frequency (f2) and the first beam width (112) is broader than the second beam width (113). (Fig. 3)



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BEAMFORMING DEVICE FOR FORMING DIFFERENT BEAMS FOR CONTROL AND DATA SIGNAL

FIELD

[0001] The disclosure relates to a beamforming device for forming beams of different frequency and beam width for a control signal and a data signal and to a method for beamforming such different beams. In particular, the disclosure relates to millimeter and centimeter wave dual control and data channel implementations in the area of next generation communication systems such as 5G, in particular using millimeter wave technology for wireless radio access networks (RAN) as well as for wireless backhaul and front haul.

BACKGROUND

[0002] Millimeter wave (mmW) communication has been considered as an important technology to be employed for modern communication standards such as the future 5G mobile system. To mitigate the severe path loss due to very high frequency, beamforming technique becomes a crucial technique to achieve reasonable link budgets. The Gbps throughput by the use of large bandwidth carriers in millimeter wavebands comes with challenges. Millimeter wave bands have more difficult propagation conditions than decimeter/ centimeter wave bands, mainly caused by an increased path loss plus higher penetration and foliage loss, increased rain attenuation, more blockage and higher atmospheric impact, e.g. 20-30 and 60 GHz bands are sensitive to H₂O and O₂ absorption effects. Otherwise millimeter wave technology allows smaller size high directional high gain directional antennas that will be used to compensate the additional losses and to establish a communication channel in a specific

direction. For maximizing range and link throughput, these directional antennas are needed at both sides, i.e. transmitter and receiver. Then the direction of the main lobe of both antennas has to point perfectly to each other. This approach works well for stationary backhaul and front-haul data as well as control channels but not for nomadic or even mobile moving devices. Here beamforming and tracking help to setup and maintain directional channels but it adds processing delay and requires huge signaling and controlling overhead at physical, medium access control and routing layers, which is challenging for control channels.

[0003] Hence, there is a need to improve efficiency of beamforming by controlling it's usage in next generation communication systems such as 5G, in particular for the use of millimeter wave technology.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The accompanying drawings are included to provide a further understanding of embodiments and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments and together with the description serve to explain principles of embodiments. Other embodiments and many of the intended advantages of embodiments will be readily appreciated as they become better understood by reference to the following detailed description.

[0005] Fig. 1 is a schematic diagram illustrating a beamforming system 100.

[0006] Fig. 2 is a block diagram illustrating a beamforming device 200 according to a first implementation.

[0007] Fig. 3 is a block diagram illustrating a beamforming device 300 according to a second implementation.

[0008] Fig. 4 is a block diagram illustrating a beamforming device 400 according to a third implementation.

[0009] Fig. 5 is a block diagram illustrating a beamforming device 500 according to a fourth implementation.

[0010] Fig. 6 is a block diagram illustrating a beamforming device 600 according to a fifth implementation.

[0011] Fig. 7 is a block diagram illustrating a beamforming device 700 according to a sixth implementation.

[0012] Fig. 8 schematically illustrates an exemplary method 800 for beamforming according to an implementation.

DETAILED DESCRIPTION

[0013] In the following detailed description, reference is made to the accompanying drawings, which form a part thereof, and in which is shown by way of illustration specific aspects in which the disclosure may be practiced. It is understood that other aspects may be utilized and structural or logical changes may be made without departing from the scope of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense, and the scope of the present disclosure is defined by the appended claims.

[0014] The following terms, abbreviations and notations are used herein:

3GPP: 3rd Generation Partnership Project,
LTE: Long Term Evolution,
LTE-A: LTE Advanced, Release 10 and higher versions of
3GPP LTE,
RF: Radio Frequency,
mmW: Millimeter Wave,
UE: User Equipment,
eNodeB: base station,
MIMO: Multiple Input Multiple Output,
AP: Access Point
CSI: Channel State Information.

[0015] The methods and devices described herein may be based on beamformers and beamforming circuits in network nodes such as eNBs, base stations, relay stations, access points (AP) and mobile stations. It is understood that comments made in connection with a described method may also hold true for a corresponding device configured to perform the method and vice versa. For example, if a specific method step is described, a corresponding device may include a unit to perform the described method step, even if such a unit is not explicitly described or illustrated in the figures. Further, it is understood that the features of the various exemplary aspects described herein may be combined with each other, unless specifically noted otherwise.

[0016] The methods and devices described herein may be implemented in wireless communication networks, in particular communication networks based on mobile communication standards such as LTE and in particular 5G. The methods and devices described below may be implemented in network nodes and base stations. The described devices may include

integrated circuits and/or passives and may be manufactured according to various technologies. For example, the circuits may be designed as logic integrated circuits, analog integrated circuits, mixed signal integrated circuits, optical circuits, memory circuits and/or integrated passives.

[0017] The methods and devices described herein may be configured to transmit and/or receive radio signals. Radio signals may be or may include radio frequency signals radiated by a radio transmitting device (or radio transmitter or sender) with a radio frequency lying in a range of about 3 Hz to 300 GHz. The frequency range may correspond to frequencies of alternating current electrical signals used to produce and detect radio waves.

[0018] The methods and devices described herein may be configured to transmit and/or receive millimeter wave (mmW) signals. Millimeter waves are radio waves in the electromagnetic spectrum from about 30 GHz to about 300 GHz. Radio frequencies in this band have wavelengths from about ten to one millimeter, giving it the name millimeter band or millimeter wave.

[0019] The methods and devices described herein after may be designed in accordance to mobile communication standards such as e.g. the ones of the 3rd Generation Partnership Project (3GPP). Long Term Evolution (LTE), LTE-Advanced, LTE-Advanced Pro and the next generation standard are mentioned as representatives for wireless communication of high-speed data for mobile phones and data terminals.

[0020] The methods and devices described hereinafter may be applied in orthogonal frequency-division multiplexing (OFDM),

single carrier (SC) or other waveform systems. For example OFDM is a scheme for encoding digital data on multiple carrier frequencies. A large number of closely spaced orthogonal sub-carrier signals may be used to carry data. Due to the orthogonality of the sub-carriers crosstalk between sub-carriers may be suppressed.

[0021] The methods and devices described hereinafter may be applied in MIMO systems and diversity receivers. Multiple-input multiple-output (MIMO) wireless communication systems employ multiple antennas, e.g. antenna arrays at the transmitter and/or at the receiver to increase system capacity and to achieve better quality of service. In spatial multiplexing mode, MIMO systems may reach higher peak data rates without increasing the bandwidth of the system by transmitting multiple data streams in parallel using the same frequency resources. A diversity receiver uses two or more antennas to improve the quality and reliability of a wireless link.

[0022] The methods and devices described hereinafter may be applied in systems comprised of beamforming antenna arrays. Beamforming or spatial filtering is a signal processing technique used in antenna arrays for directional signal transmission or reception. This is achieved by combining elements in a phased array in such a way that signals at particular angles experience constructive interference while others experience destructive interference. Beamforming can be used at both the transmitting and receiving ends in order to achieve spatial selectivity. The improvement compared with omnidirectional reception/transmission is known as the directivity of the element. To change the directionality of the array when transmitting, a beamformer controls the phase

and relative amplitude of the signal at each transmitter, in order to create a pattern of constructive and destructive interference in the wavefront.

[0023] During reception, information from different sensors of the antenna array is combined in a way where the expected pattern of radiation is preferentially observed. It is envisioned that the pencil beam with very narrow beam widths, e.g., 5 to 15 degrees, offering high beamforming gain is to be widely used. Beamforming may be implemented by digital, hybrid and analog beamforming. In practical mmW systems, hybrid beamformers comprised of modular antenna arrays using phase shifter networks are usually employed. To transmit multiple parallel beams, mmW access point (AP) can be equipped with multiple beamformers, each of which illuminates a different beam direction. In addition to higher throughput, modern communication standards such as the future 5G mobile system are also targeting lower latency and better spectrum efficiency.

[0024] The methods and devices described hereinafter may be applied in baseband processors (BPs) and baseband circuits of mobile phones and other devices. Mobile phones and other devices typically require considerable processing power to control their computational and communications functions. The Central Processing Unit (CPU) of such a device allows for many functions, and often includes several software applications and drivers. Most mobile communications devices also include a Baseband Processor (BP), separate from the CPU. Generally, it manages the radio control functions, such as signal generation, modulation, encoding, as well as frequency shifting. It can also manage the transmission of signals. The baseband processor is typically located on the

same circuit board as the CPU, but consists of a separate radio electronics component. It can therefore have a different programming interface and control software. Some baseband radio processor models can handle many channels at once, usually while processing all receive and transmit demands. The BP can also search for mobile signals and track them, as well as select antennas automatically. In many cases, a baseband processor is contained in a common integrated circuit package.

[0025] The baseband processor or baseband circuit can implement control plane and data plane processing. For mobile signal processing the BP can use a control plane and data plane split, where for example an omnidirectional control channel on LTE is used to maintain good coverage and reliability for the control plane and achieve high throughput and good distance for the data plane via a directional data channel on millimeter wave.

[0026] In the following, embodiments are described with reference to the drawings, wherein like reference numerals are generally utilized to refer to like elements throughout. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of one or more aspects of embodiments. However, it may be evident to a person skilled in the art that one or more aspects of the embodiments may be practiced with a lesser degree of these specific details. The following description is therefore not to be taken in a limiting sense.

[0027] The various aspects summarized may be embodied in various forms. The following description shows by way of illustration various combinations and configurations in which

the aspects may be practiced. It is understood that the described aspects and/or embodiments are merely examples, and that other aspects and/or embodiments may be utilized and structural and functional modifications may be made without departing from the scope of the present disclosure.

[0028] Fig. 1 is a schematic diagram illustrating a beamforming system 100. The beamforming system 100 includes a beamforming device implemented in an access point (AP) 108, e.g. a base station, and a plurality of mobile devices, also denoted as mobile stations or user equipments 101, 102, 103, 104, 105. The beamforming device includes a baseband circuit (BB) or a baseband processor and a transceiver. The baseband circuit provides a control signal in a control plane and a data signal in a data plane. The transceiver converts the control signal to a first frequency f_1 , 114 of a first radio carrier and forms a first transmission beam 110 having a first beam width 112 based on the converted control signal 310. The transceiver further converts the data signal to a second frequency f_2 , 115 of a second radio carrier and forms a second transmission beam 111 having a second beam width 113 based on the converted data signal. The first frequency f_1 , 114 is lower, in particular significantly lower, than the second frequency f_2 , 115 and the first beam width 112 is broader, in particular significantly broader, than the second beam width 113.

[0029] The transceiver may form the first transmission beam 110 as a non-directional beam or an omni-directional beam and the second transmission beam 111 as a directional beam.

[0030] A range of both beams 110, 111 may depend on their beam frequencies 114, 115 or wavelengths and their beam

widths 112, 113 or beam angles. A higher frequency reduces the range of the beams due to material attenuation for high frequencies while a lower frequency increases their range. A broad beam width also reduces the range of the beams due to energy radiation over a larger space while a small beam width increases their range due to focused energy radiation. Therefore, the transceiver may adjust a range of the first beam 110 by controlling the frequency f_1 , 114 and beam width 112 of the first beam 110 and the transceiver may further adjust a range of the second beam 111 by controlling the frequency f_2 , 115 and beam width 113 of the second beam 111. Hence, the transceiver may adjust the first frequency f_1 , 114, the second frequency f_2 , 115, the first beam width 112 and the second beam width 113 in order to form the first transmission beam 110 and the second transmission beam 111 having approximately a same range. Then, all UEs 101, 102, 103, 104, 105 may be covered by the first beam 110 and hence controlled by the control signal and the second beam 111 may be directed to a respective one of the UEs 101, 102, 103, 104, 105 in order to support a high antenna gain for data transmission using the data signal.

[0031] A ratio between the first frequency f_1 , 114 and the second frequency f_2 , 115 may be tuned according to an inherent transceiver link reliability. The link reliability may be determined by using CSI (channel state information), i.e. a measure indicating a quality of the radio link or radio channel.

[0032] The first radio carrier and the second radio carrier may be millimeter wave carriers. That is, both the control signal and the data signal may be transmitted by using a millimeter wave carrier. Alternatively, the first radio

carrier may be a centimeter wave carrier and the second radio carrier a millimeter wave carrier. I.e. the control signal may be transmitted by using a decimeter/ centimeter wave carrier and the data signal may be transmitted by using a millimeter wave carrier.

[0033] The control signal may be a downlink control signal for transmission to a user device 101, 102, 103, 104, 105. The data signal may be a downlink data signal for transmission to the user device 101, 102, 103, 104, 105. The control signal may be an uplink control signal for transmission to an access point (AP). The data signal may be an uplink data signal for transmission to the access point.

[0034] Fig. 2 is a block diagram illustrating a beamforming device 200 according to a first implementation.

[0035] The beamforming device 200 includes a baseband circuit (BB) including a control plane 210 or control section for generating a control signal and a data plane 211 or data section for generating a data signal. The beamforming device 200 further includes a transceiver that may operate at a first frequency f_1 , e.g. a first millimeter wave 220 and at a second frequency f_2 , e.g. a second millimeter wave 221. The transceiver converts the control signal to the first frequency f_1 of a first radio carrier, e.g. a first mm wave carrier and forms a first transmission beam, e.g. a first transmission beam 110 as described above with respect to Fig. 1, having a first beam width 112 based on the converted control signal 310. The transceiver further converts the data signal to a second frequency f_2 of a second radio carrier, e.g. a second mm wave carrier and forms a second transmission beam, e.g. a second transmission beam 111 as described above

with respect to Fig. 1, having a second beam width 113 based on the converted data signal. The first frequency f_1 , 114 is lower, in particular significant lower, than the second frequency f_2 , 115 and the first beam width 112 is broader, in particular significant broader, than the second beam width 113. The first transmission beam is coupled to a first antenna or antenna array 230, e.g. an omnidirectional or non-directional antenna or antenna array. The second transmission beam is coupled to a second antenna or antenna array 231, e.g. a directional antenna or antenna array.

[0036] In one exemplary implementation of the beamforming device 200, the device is based upon the usage of at least two millimeter wave carriers ($mm1$, $mm2$), whereas one carrier ($mm2$) uses directional high gain antennas 231 with beamforming and tracking for the data channel, whereas the other carrier ($mm1$) uses an omnidirectional (or non-directional) antenna configuration 230 for the control channel. The control channel millimeter wave carrier frequency f_1 and bandwidth is considerably lower than the data channel frequency f_2 . The transceiver is comprised of at least one transmitter and one receiver, where both can support at least two different millimeter wave carriers ($mm1$, $mm2$). The control channel on the lower frequency carrier ($mm1$) is transmitted and received via an omnidirectional antenna 230 and the data channel on the second carrier ($mm2$) is transmitted and received via a directional antenna 231.

[0037] The beamforming device 200 avoids the drawbacks as illustrated in the introduction by using at least two millimeter wave carriers at access point (AP) and user equipment (UE), whereas one carrier ($mm2$) uses directional high gain antennas 231 or antenna arrays with beamforming and

tracking for the data channel and the other carrier (mm1) uses an omnidirectional (or non-directional) antenna configuration 230 or antenna array for the control channel. A non-directional antenna or antenna array may produce a beam that is not directed to a specific direction, instead the beam is radiated over a specific space section, e.g. spanning an angle of for example 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260, 270, 280, 290, 300, 310, 320, 330, 340, 350 degrees up to the full space of 360 degrees. This specific case of radiation over the full space of 360 degrees is also referred to as an omnidirectional antenna or antenna array. A directional antenna or antenna array may produce a beam that is directed to a specific direction, e.g. a pencil beam spanning an angle of for example 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15 degrees.

[0038] The control channel millimeter wave carrier frequency f_1 and bandwidth is considerably lower than the data channel frequency f_2 . The control channel allows transmitting system control information in various directions. This allows receivers with omnidirectional antenna and multiple receiver paths to collect energy arriving from different paths. Therefore the procedure resembles the characteristics of a mobile radio channel in decimeter/ centimeter wave bands. The lower carrier frequency f_1 allows larger coverage for the control plane 210 than the one f_2 of the data plane 211 supporting, broad- and multi- cast of control signals, handover and channel access. It may be chosen in such a way, that the transmission range allows either to cover the transmission range of the directional data plane 211 in case of stand-alone small cell or to cover the full cell including a slight overlap in neighborhood cells in case of overlapping

small cells. The high data throughput channel is provisioned by the directional antenna system 231.

[0039] Fig. 3 is a block diagram illustrating a beamforming device 300 according to a second implementation. The beamforming device 300 includes a baseband circuit 301 and a transceiver circuit 302. The baseband circuit 301 is configured to provide a control signal 310 and a data signal 311. The transceiver circuit 302 is configured to convert the control signal 310 to a first frequency f_1 of a first radio carrier 314 and to form a first transmission beam 110, e.g. according to the description of Fig. 1, having a first beam width 112 based on the converted control signal 310. The transceiver circuit 302 is further configured to convert the data signal 311 to a second frequency f_2 of a second radio carrier 315, and to form a second transmission beam 111, e.g. according to the description of Fig. 1, having a second beam width 113 based on the converted data signal 311. The first frequency f_1 is lower than the second frequency f_2 and the first beam width 112 is broader than the second beam width 113.

[0040] The transceiver circuit 302 may form the first transmission beam 110 as a non-directional beam or an omnidirectional beam and to form the second transmission beam 111 as a directional beam. The transceiver circuit 302 may adjust the first frequency f_1 , the second frequency f_2 , the first beam width 112 and the second beam width 113 in order to form the first transmission beam 110 and the second transmission beam 111 having approximately a same range, e.g. corresponding to the description of Fig. 1. A ratio between the first frequency f_1 and the second frequency f_2 may be tuned according to an inherent transceiver link reliability.

[0041] The first radio carrier 314 and the second radio carrier (315) are millimeter wave carriers. Alternatively, the first radio carrier 314 may be a decimeter/ centimeter wave carrier and the second radio carrier 315 a millimeter wave carrier.

[0042] The control signal 310 may be a downlink control signal for transmission to a user device. The data signal 311 may be a downlink data signal for transmission to the user device. The control signal 310 may be an uplink control signal for transmission to an access point. The data signal 311 may be an uplink data signal for transmission to the access point.

[0043] The beamforming device 300 may have a single transceiver 302 that may transmit and receive a plurality of beams 110, 111, e.g. by adjusting a plurality of respective beamforming controls assigned for generating the plurality of beams 110, 111. The beams 110, 111 may be generated in an analog, hybrid or a digital part of the beamforming device 300, i.e. by applying analog beamforming or hybrid and digital beamforming controls. The beamforming device 300 may have an antenna port for coupling the transceiver 302 with an (external) antenna or (external) antenna array. The antenna array may be a static antenna array, i.e. an antenna array which generates the beams solely by applying specific beamforming controls to the individual antennas of the antenna array. There is no need to individually move the antennas with respect to each other. However, the antenna array as a whole may be moved, for example by a drive, e.g. an electric drive.

[0044] In one exemplary implementation of the beamforming device 300, the baseband circuit 301 is configured to provide a plurality of control signals 310 and a plurality of data signals 311; and the transceiver circuit 302 is configured to: convert each control signal 310 to a frequency 114 of a first radio carrier 314 assigned to the control signal 310, form for each converted control signal 310 a first transmission beam 110 having a first beam width 112, convert each data signal 311 to a frequency 115 of a second radio carrier 315 assigned to the data signal 311, and form for each converted data signal 311 a second transmission beam 111 having a second beam width 113, wherein for each control signal 310 and data signal 311 the frequency 114 of the first radio carrier 314 is lower than the frequency 115 of the second radio carrier 315 and the first beam width 112 is broader than the second beam width 113.

[0045] In the implementation indicated above, the transceiver circuit 302 may be configured to adjust for each control signal 310 and data signal 311 the frequency 114 of the first radio carrier 314, the frequency 115 of the second radio carrier 315, the first beam width 112 and the second beam width 113 in order to form the first transmission beam 110 and the second transmission beam 111 having approximately a same range. For each control signal 310 and data signal 311 a ratio between the frequency 114 of the first radio carrier 314 and the frequency 115 of the second radio carrier 315 may be tuned according to an inherent transceiver link reliability.

[0046] In the implementation indicated above, for each control signal 310 and data signal 311 the first radio carrier 314 may be a millimeter wave carrier or a decimeter/

centimeter wave carrier and the second radio carrier 315 may be a millimeter wave carrier. The transceiver circuit 302 may be configured to form each first transmission beam 110 for controlling a plurality of user devices 101, 102, 103, 104, 105 and to form each second transmission beam 111 for serving the plurality of user devices 101, 102, 103, 104, 105.

[0047] Fig. 4 is a block diagram illustrating a beamforming device 400 according to a third implementation. The beamforming device 400 may be an implementation of the beamforming device 300 described above with respect to Fig. 3. The beamforming device 400 includes a baseband circuit 301 as described above with respect to Fig. 3 and a transceiver circuit 402.

[0048] The transceiver circuit 402 is configured to convert the control signal 310 to a first frequency f_1 of a first radio carrier 314 and to form a first transmission beam 410, e.g. a beam 110 as described above with respect to Figures 1 and 3, having a first beam width 112 based on the converted control signal 310. The transceiver circuit 402 is further configured to convert the data signal 311 to a second frequency f_2 of a second radio carrier 315, and to form a second transmission beam 411, e.g. a beam 111 as described above with respect to Figures 1 and 3, having a second beam width 113 based on the converted data signal 311. The first frequency f_1 is lower than the second frequency f_2 and the first beam width 112 is broader than the second beam width 113.

[0049] The transceiver circuit 402 may include a transmitter section 403 configured to form the first transmission beam 410 and the second transmission beam 411. The transceiver

circuit 402 may further include a receiver section 404 configured to receive a first reception beam 412, e.g. a beam 110 as described above with respect to Figs. 1 and 3, and a second reception beam 413, e.g. a beam 111 as described above with respect to Figs. 1 and 3.

[0050] The beamforming device 400 may include an antenna port 406 configured to be coupled to an antenna array 407. The beamforming device 400 may include a control unit 405 coupled between the transceiver circuit 402 and the antenna array 407. The control unit 405 may be configured to switch the antenna array 407 between non-directional or omnidirectional for the first transmission beam 410 and directional for the second transmission beam 411. A switch control signal 432 may be used by the control unit 405 to control the transceiver circuit 402 for transmitting 434 the respective transmission beam.

[0051] The control unit 405 may be configured to switch between coupling the first reception beam 412 or the second reception beam 413 to the transceiver circuit 402. A switch control signal 432 may be used by the control unit 405 to control the transceiver circuit 402 for receiving 434 the respective reception beam.

[0052] Fig. 5 is a block diagram illustrating a beamforming device 500 according to a fourth implementation. The beamforming device 500 may be an implementation of the beamforming device 400 described above with respect to Fig. 4. The beamforming device 500 includes a baseband circuit 301 and a transceiver circuit 402 as described above with respect to Fig. 4.

[0053] The transceiver circuit 402 is configured to convert the control signal 310 to a first frequency f_1 of a first radio carrier 314 and to form a first transmission beam 410 having a first beam width 112 based on the converted control signal 310. The transceiver circuit 402 is further configured to convert the data signal 311 to a second frequency f_2 of a second radio carrier 315, and to form a second transmission beam 411 having a second beam width 113 based on the converted data signal 311. The first frequency f_1 is lower than the second frequency f_2 and the first beam width 112 is broader than the second beam width 113.

[0054] The transceiver circuit 402 may include a transmitter section 403 configured to form the first transmission beam 410 and the second transmission beam 411. The transceiver circuit 402 may further include a receiver section 404 configured to receive a first reception beam 412 and a second reception beam 413.

[0055] The beamforming device 500 may include a first antenna port 511 configured to be coupled to a first antenna array 507 and a second antenna port 512 configured to be coupled to a second antenna array 508.

[0056] The transmitter section 403 may be configured to couple the first transmission beam 410 to the first antenna port 511 and the second transmission beam 411 to the second antenna port 512. The receiver section 404 may be configured to receive the first reception beam 412 from the first antenna port 511 and the second reception beam 413 from the second antenna port 512.

[0057] The first antenna port 511 may be configured to be coupled to a non-directional or omnidirectional antenna array 508 and the second antenna port 512 may be configured to be coupled to a directional antenna array 508.

[0058] Fig. 6 is a block diagram illustrating a beamforming device 600 according to a fifth implementation. The beamforming device 600 may be an implementation of the beamforming device 400 described above with respect to Fig. 4 and/or the beamforming device 500 described above with respect to Fig. 5. The beamforming device 600 includes a baseband circuit 301 and a transceiver circuit 402 as described above with respect to Fig. 4.

[0059] The transceiver circuit 402 is configured to convert the control signal 310 to a first frequency f_1 of a first radio carrier 314 and to form a first transmission beam 410 having a first beam width 112 based on the converted control signal 310. The transceiver circuit 402 is further configured to convert the data signal 311 to a second frequency f_2 of a second radio carrier 315, and to form a second transmission beam 411 having a second beam width 113 based on the converted data signal 311. The first frequency f_1 is lower than the second frequency f_2 and the first beam width 112 is broader than the second beam width 113.

[0060] The transceiver circuit 402 may include a transmitter section 403 configured to form the first transmission beam 410 and the second transmission beam 411. The transceiver circuit 402 may further include a receiver section 404 configured to receive a first reception beam 412 and a second reception beam 413.

[0061] The beamforming device 500 may include a first antenna port 511 configured to be coupled to a first antenna array 507 and a second antenna port 512 configured to be coupled to a second antenna array 508.

[0062] The transmitter section 403 may be configured to couple the first transmission beam 410 to the first antenna port 511 and the second transmission beam 411 to the second antenna port 512.

[0063] The beamforming device 600 may include a third antenna port 613 configured to be coupled to a third antenna array 609. The beamforming device 600 may include a control unit 405 coupled between the transceiver circuit 402 and the third antenna array 609. The receiver section 404 may be configured to receive the first reception beam 412 and the second reception beam 413 from the third antenna port 613. The control unit 405 may be configured to switch the third antenna array 609 between non-directional or omnidirectional for the first reception beam 412 and directional for the second reception beam 413.

[0064] The first antenna port 511 may be configured to be coupled to a non-directional or omnidirectional antenna array 507 and the second antenna port 512 may be configured to be coupled to a directional antenna array 508. The third antenna port 613 may be configured to be coupled to an antenna array that may be switched between non-directional or omnidirectional and directional operation.

[0065] Fig. 7 is a block diagram illustrating a beamforming device 700 according to a sixth implementation. The beamforming device 700 may be an implementation of the

beamforming device 400 described above with respect to Fig. 4 and/or the beamforming device 500 described above with respect to Fig. 5 and/or the beamforming device 600 described above with respect to Fig. 6. The beamforming device 600 includes a baseband circuit 301 and a transceiver circuit 402 as described above with respect to Fig. 4.

[0066] The transceiver circuit 402 is configured to convert the control signal 310 to a first frequency f_1 of a first radio carrier 314 and to form a first transmission beam 410 having a first beam width 112 based on the converted control signal 310. The transceiver circuit 402 is further configured to convert the data signal 311 to a second frequency f_2 of a second radio carrier 315, and to form a second transmission beam 411 having a second beam width 113 based on the converted data signal 311. The first frequency f_1 is lower than the second frequency f_2 and the first beam width 112 is broader than the second beam width 113.

[0067] The transceiver circuit 402 may include a transmitter section 403 configured to form the first transmission beam 410 and the second transmission beam 411. The transceiver circuit 402 may further include a receiver section 404 configured to receive a first reception beam 412 and a second reception beam 413.

[0068] The beamforming device 700 may include a first antenna port 511 configured to be coupled to a first antenna array 507 and a second antenna port 512 configured to be coupled to a second antenna array 508. The receiver section 404 may be configured to receive the first reception beam 412 from the first antenna port 511 and the second reception beam 413 from the second antenna port 512.

[0069] The beamforming device 700 may include a third antenna port 613 configured to be coupled to a third antenna array 609. The beamforming device 700 may include a control unit 405 coupled between the transceiver circuit 402 and the third antenna array 609. The control unit 405 may be configured to switch the third antenna array 609 between non-directional or omnidirectional for the first transmission beam 410 and directional for the second transmission beam 411.

[0070] The first antenna port 511 may be configured to be coupled to a non-directional or omnidirectional antenna array 507 and the second antenna port 512 may be configured to be coupled to a directional antenna array 508. The third antenna port 613 may be configured to be coupled to an antenna array that may be switched between non-directional or omnidirectional and directional operation.

[0071] Fig. 8 schematically illustrates an exemplary method 800 for beamforming according to an implementation. The method 800 includes generating 801 a control signal and a data signal, e.g. by using a baseband circuit 301 as described above with respect to Figures 3 to 7. The method 800 includes converting 802 the control signal to a first frequency of a first radio carrier; forming 803 a first transmission beam having a first beam width based on the converted control signal; converting 804 the data signal to a second frequency of a second radio carrier; and forming 805 a second transmission beam having a second beam width based on the converted data signal, e.g. by using a transceiver 302, 402 as described above with respect to Figures 3 to 7. The first frequency is lower than the second frequency 806 and

the first beam width is broader than the second beam width 806.

[0072] The method 800 may further include forming 803 the first transmission beam as a non-directional beam or an omnidirectional beam; and forming 805 the second transmission beam as a directional beam, e.g. as described above with respect to Figures 3 to 7.

[0073] The method 800 may further include adjusting the first frequency, the second frequency, the first beam width and the second beam width in order to form the first transmission beam and the second transmission beam having approximately a same range beam, e.g. as described above with respect to Figures 3 to 7.

[0074] The methods, systems and devices described herein may be implemented as software in a Digital Signal Processor (DSP), in a micro-controller or in any other side-processor or as hardware circuit on a chip or within an application specific integrated circuit (ASIC).

[0075] Embodiments described in this disclosure can be implemented in digital electronic circuitry, or in computer hardware, firmware, software, or in combinations thereof, e.g. in available hardware of mobile devices or in new hardware dedicated for processing the methods described herein.

[0076] The present disclosure also supports a computer program product including computer executable code or computer executable instructions that, when executed, causes at least one computer to execute the performing and computing

blocks described herein, in particular the method 400 or the algorithm 600 as described above with respect to Figs. 4 and 6. Such a computer program product may include a readable storage medium storing program code thereon for use by a processor, the program code comprising instructions for performing any of the method 400 or the algorithm 600 as described above.

EXAMPLES

[0077] The following examples pertain to further embodiments. Example 1 is a beamforming device, comprising: a baseband circuit configured to provide a control signal and a data signal; and a transceiver circuit configured to: convert the control signal to a first frequency of a first radio carrier, form a first transmission beam having a first beam width based on the converted control signal, convert the data signal to a second frequency of a second radio carrier, and form a second transmission beam having a second beam width based on the converted data signal, wherein the first frequency is lower than the second frequency and the first beam width is broader than the second beam width.

[0078] In Example 2, the subject matter of Example 1 can optionally include that the transceiver circuit is configured to form the first transmission beam as a non-directional beam or an omni-directional beam and to form the second transmission beam as a directional beam.

[0079] In Example 3, the subject matter of any one of Examples 1-2 can optionally include that the transceiver circuit is configured to adjust the first frequency, the second frequency, the first beam width and the second beam

width in order to form the first transmission beam and the second transmission beam having approximately a same range.

[0080] In Example 4, the subject matter of any one of Examples 1-3 can optionally include that a ratio between the first frequency and the second frequency is tuned according to an inherent transceiver link reliability.

[0081] In Example 5, the subject matter of any one of Examples 1-4 can optionally include that the first radio carrier and the second radio carrier are millimeter wave carriers.

[0082] In Example 6, the subject matter of any one of Examples 1-4 can optionally include that the first radio carrier is a decimeter/ centimeter wave carrier and the second radio carrier is a millimeter wave carrier.

[0083] In Example 7, the subject matter of any one of Examples 1-6 can optionally include that the control signal is a downlink control signal for transmission to a user device; and that the data signal is a downlink data signal for transmission to the user device.

[0084] In Example 8, the subject matter of any one of Examples 1-7 can optionally include that the control signal is an uplink control signal for transmission to an access point; and that the data signal is an uplink data signal for transmission to the access point.

[0085] In Example 9, the subject matter of any one of Examples 1-8 can optionally include that the transceiver circuit comprises: a transmitter section configured to form

the first transmission beam and the second transmission beam; and a receiver section configured to receive a first reception beam and a second reception beam.

[0086] In Example 10, the subject matter of Example 9 can optionally include an antenna port configured to be coupled to an antenna array; and a control unit coupled between the transceiver circuit and the antenna array, wherein the control unit is configured to switch the antenna array between non-directional or omnidirectional for the first transmission beam and directional for the second transmission beam.

[0087] In Example 11, the subject matter of Example 10 can optionally include that the control unit is configured to switch between coupling the first reception beam or the second reception beam to the transceiver circuit.

[0088] In Example 12, the subject matter of Example 9 can optionally include a first antenna port configured to be coupled to a first antenna array; and a second antenna port configured to be coupled to a second antenna array, wherein the transmitter section is configured to couple the first transmission beam to the first antenna port and the second transmission beam to the second antenna port.

[0089] In Example 13, the subject matter of Example 12 can optionally include that the receiver section is configured to receive the first reception beam from the first antenna port and the second reception beam from the second antenna port.

[0090] In Example 14, the subject matter of Example 12 can optionally include a third antenna port configured to be

coupled to a third antenna array; and a control unit coupled between the transceiver circuit and the third antenna array, wherein the receiver section is configured to receive the first reception beam and the second reception beam from the third antenna port, and wherein the control unit is configured to switch the third antenna array between non-directional or omnidirectional for the first reception beam and directional for the second reception beam.

[0091] In Example 15, the subject matter of Example 9 can optionally include a first antenna port configured to be coupled to a first antenna array; and a second antenna port configured to be coupled to a second antenna array, wherein the receiver section is configured to receive the first reception beam from the first antenna port and the second reception beam from the second antenna port.

[0092] In Example 16, the subject matter of Example 15 can optionally include a third antenna port configured to be coupled to a third antenna array; and a control unit coupled between the transceiver circuit and the third antenna array, wherein the control unit is configured to switch the third antenna array between non-directional or omnidirectional for the first transmission beam and directional for the second transmission beam.

[0093] In Example 17, the subject matter of any one of Examples 12-16 can optionally include that the first antenna port is configured to be coupled to a non-directional or omnidirectional antenna array, and that the second antenna port is configured to be coupled to a directional antenna array.

[0094] Example 18 is a beamforming device, comprising: a baseband circuit configured to provide a plurality of control signals and a plurality of data signals; and a transceiver circuit configured to: convert each control signal to a frequency of a first radio carrier assigned to the control signal, form for each converted control signal a first transmission beam having a first beam width, convert each data signal to a frequency of a second radio carrier assigned to the data signal, and form for each converted data signal a second transmission beam having a second beam width, wherein for each control signal and data signal the frequency of the first radio carrier is lower than the frequency of the second radio carrier and the first beam width is broader than the second beam width.

[0095] In Example 19, the subject matter of Example 18 can optionally include that the transceiver circuit is configured to adjust for each control signal and data signal the frequency of the first radio carrier, the frequency of the second radio carrier, the first beam width and the second beam width in order to form the first transmission beam and the second transmission beam having approximately a same range.

[0096] In Example 20, the subject matter of any one of Examples 18-19 can optionally include that for each control signal and data signal a ratio between the frequency of the first radio carrier and the frequency of the second radio carrier is tuned according to an inherent transceiver link reliability.

[0097] In Example 21, the subject matter of any one of Examples 18-20 can optionally include that for each control

signal and data signal the first radio carrier is a millimeter wave carrier or a decimeter/ centimeter wave carrier and the second radio carrier is a millimeter wave carrier.

[0098] In Example 22, the subject matter of any one of Examples 18-21 can optionally include that the transceiver circuit is configured to form each first transmission beam for controlling a plurality of user devices and to form each second transmission beam for serving the plurality of user devices.

[0099] Example 23 is a method for beamforming, the method comprising: generating a control signal and a data signal; converting the control signal to a first frequency of a first radio carrier; forming a first transmission beam having a first beam width based on the converted control signal; converting the data signal to a second frequency of a second radio carrier; and forming a second transmission beam having a second beam width based on the converted data signal, wherein the first frequency is lower than the second frequency, and wherein the first beam width is broader than the second beam width.

[0100] In Example 24, the subject matter of Example 23 can optionally include: forming the first transmission beam as a non-directional beam or an omni-directional beam; and forming the second transmission beam as a directional beam.

[0101] In Example 25, the subject matter of any one of Examples 23-24 can optionally include: adjusting the first frequency, the second frequency, the first beam width and the second beam width in order to form the first transmission

beam and the second transmission beam having approximately a same range.

[0102] In Example 26, the subject matter of any one of Examples 23-25 can optionally include: tuning a ratio between the first frequency and the second frequency according to an inherent transceiver link reliability.

[0103] In Example 27, the subject matter of any one of Examples 23-26 can optionally include that the first radio carrier and the second radio carrier are millimeter wave carriers.

[0104] In Example 28, the subject matter of any one of Examples 23-26 can optionally include that the first radio carrier is a decimeter/ centimeter wave carrier and the second radio carrier is a millimeter wave carrier.

[0105] In Example 29, the subject matter of any one of Examples 23-28 can optionally include that the control signal is a downlink control signal for transmission to a user device; and that the data signal is a downlink data signal for transmission to the user device.

[0106] In Example 30, the subject matter of any one of Examples 23-28 can optionally include that the control signal is an uplink control signal for transmission to an access point; and that the data signal is an uplink data signal for transmission to the access point.

[0107] Example 31 is a computer readable non-transitory medium on which computer instructions are stored which when

executed by a computer, cause the computer to perform the method of one of Examples 23 to 30.

[0108] Example 32 is a beamforming device, comprising: means for generating a control signal and a data signal; means for converting the control signal to a first frequency of a first radio carrier; means for forming a first transmission beam having a first beam width based on the converted control signal; means for converting the data signal to a second frequency of a second radio carrier; and means for forming a second transmission beam having a second beam width based on the converted data signal, wherein the first frequency is lower than the second frequency, and wherein the first beam width is broader than the second beam width.

[0109] In Example 33, the subject matter of Example 32 can optionally include: means for forming the first transmission beam as a non-directional beam or an omni-directional beam; and means for forming the second transmission beam as a directional beam.

[0110] In Example 34, the subject matter of any one of Examples 32-33 can optionally include means for adjusting the first frequency, the second frequency, the first beam width and the second beam width in order to form the first transmission beam and the second transmission beam having approximately a same range.

[0111] In Example 35, the subject matter of any one of Examples 32-34 can optionally include means for tuning a ratio between the first frequency and the second frequency according to an inherent transceiver link reliability.

[0112] Example 36 is a beamforming circuit, comprising: a baseband circuit configured to provide a plurality of control signals and a plurality of data signals; and a transceiver circuit configured to: convert each control signal to a frequency of a first radio carrier assigned to the control signal, form for each converted control signal a first transmission beam having a first beam width, convert each data signal to a frequency of a second radio carrier assigned to the data signal, and form for each converted data signal a second transmission beam having a second beam width, wherein for each control signal and data signal the frequency of the first radio carrier is lower than the frequency of the second radio carrier and the first beam width is broader than the second beam width.

[0113] In Example 37, the subject matter of Example 36 can optionally include that the transceiver circuit is configured to adjust for each control signal and data signal the frequency of the first radio carrier, the frequency of the second radio carrier (315), the first beam width and the second beam width in order to form the first transmission beam and the second transmission beam having approximately a same range.

[0114] In Example 38, the subject matter of any one of Examples 36-37 can optionally include that for each control signal and data signal a ratio between the frequency of the first radio carrier and the frequency of the second radio carrier is tuned according to an inherent transceiver link reliability.

[0115] Example 39 is a beamforming system, comprising: a baseband subsystem configured to provide a control signal and

a data signal; and a transceiver subsystem configured to: convert the control signal to a first frequency of a first radio carrier, form a first transmission beam having a first beam width based on the converted control signal, convert the data signal to a second frequency of a second radio carrier, and form a second transmission beam having a second beam width based on the converted data signal, wherein the first frequency is lower than the second frequency and the first beam width is broader than the second beam width.

[0116] In Example 40, the subject matter of Example 39 can optionally include that the transceiver subsystem is configured to form the first transmission beam as a non-directional beam or an omni-directional beam and to form the second transmission beam as a directional beam.

[0117] In Example 41, the subject matter of any one of Examples 39-40 can optionally include that the transceiver subsystem is configured to adjust the first frequency, the second frequency, the first beam width and the second beam width in order to form the first transmission beam and the second transmission beam having approximately a same range.

[0118] In Example 42, the subject matter of any one of Examples 39-41 can optionally include that the transceiver subsystem is configured to tune a ratio between the first frequency and the second frequency according to an inherent transceiver link reliability.

[0119] Example 26 is a computer readable medium on which computer instructions are stored which when executed by a computer, cause the computer to perform the method of one of Examples 11 to 20.

[0120] In addition, while a particular feature or aspect of the disclosure may have been disclosed with respect to only one of several implementations, such feature or aspect may be combined with one or more other features or aspects of the other implementations as may be desired and advantageous for any given or particular application. Furthermore, to the extent that the terms "include", "have", "with", or other variants thereof are used in either the detailed description or the claims, such terms are intended to be inclusive in a manner similar to the term "comprise". Furthermore, it is understood that aspects of the disclosure may be implemented in discrete circuits, partially integrated circuits or fully integrated circuits or programming means. Also, the terms "exemplary", "for example" and "e.g." are merely meant as an example, rather than the best or optimal.

[0121] Although specific aspects have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a variety of alternate and/or equivalent implementations may be substituted for the specific aspects shown and described without departing from the scope of the present disclosure. This application is intended to cover any adaptations or variations of the specific aspects discussed herein.

[0122] Although the elements in the following claims are recited in a particular sequence with corresponding labeling, unless the claim recitations otherwise imply a particular sequence for implementing some or all of those elements, those elements are not necessarily intended to be limited to being implemented in that particular sequence.

CLAIMS

1. A beamforming device, comprising:
a baseband circuit configured to provide a control signal and a data signal; and
a transceiver circuit configured to:
convert the control signal to a first frequency of a first radio carrier,
form a first transmission beam having a first beam width (113) based on the converted control signal,
convert the data signal to a second frequency of a second radio carrier, and
form a second transmission beam having a second beam width based on the converted data signal,
wherein the first frequency is lower than the second frequency and the first beam width is broader than the second beam width.
2. The beamforming device of claim 1,
wherein the transceiver circuit is configured to form the first transmission beam as a non-directional beam or an omni-directional beam and to form the second transmission beam as a directional beam.
3. The beamforming device of claim 1 or 2,
wherein the transceiver circuit is configured to adjust the first frequency, the second frequency, the first beam width and the second beam width in order to form the first transmission beam and the second transmission beam having approximately a same range.
4. The beamforming device of claim 1 or 2,

wherein a ratio between the first frequency and the second frequency is tuned according to an inherent transceiver link reliability.

5. The beamforming device of claim 1 or 2,
wherein the first radio carrier and the second radio carrier are millimeter wave carriers.

6. The beamforming device of claim 1 or 2,
wherein the first radio carrier is a decimeter/
centimeter wave carrier and the second radio carrier is a
millimeter wave carrier.

7. The beamforming device of claim 1 or 2,
wherein the control signal is a downlink control
signal for transmission to a user device; and
wherein the data signal is a downlink data signal for
transmission to the user device.

8. The beamforming device of claim 1 or 2,
wherein the control signal is an uplink control
signal for transmission to an access point; and
wherein the data signal is an uplink data signal for
transmission to the access point.

9. The beamforming device of claim 1 or 2, wherein the
transceiver circuit comprises:

a transmitter section configured to form the first
transmission beam and the second transmission beam; and

a receiver section configured to receive a first
reception beam and a second reception beam.

10. The beamforming device of claim 9, comprising:

an antenna port configured to be coupled to an antenna array; and

a control unit coupled between the transceiver circuit and the antenna array, wherein the control unit is configured to switch the antenna array between non-directional or omnidirectional for the first transmission beam and directional for the second transmission beam.

11. The beamforming device of claim 10,
wherein the control unit is configured to switch between coupling the first reception beam or the second reception beam to the transceiver circuit.

12. The beamforming device of claim 9, comprising:
a first antenna port configured to be coupled to a first antenna array; and
a second antenna port configured to be coupled to a second antenna array,
wherein the transmitter section is configured to couple the first transmission beam to the first antenna port and the second transmission beam to the second antenna port.

13. The beamforming device of claim 12,
wherein the receiver section is configured to receive the first reception beam from the first antenna port and the second reception beam from the second antenna port.

14. The beamforming device of claim 12, comprising:
a third antenna port configured to be coupled to a third antenna array; and
a control unit coupled between the transceiver circuit and the third antenna array,

wherein the receiver section is configured to receive the first reception beam and the second reception beam from the third antenna port, and

wherein the control unit is configured to switch the third antenna array between non-directional or omnidirectional for the first reception beam and directional for the second reception beam.

15. The beamforming device of claim 9, comprising:

a first antenna port configured to be coupled to a first antenna array; and

a second antenna port configured to be coupled to a second antenna array,

wherein the receiver section is configured to receive the first reception beam from the first antenna port and the second reception beam from the second antenna port.

16. The beamforming device of claim 15, comprising:

a third antenna port configured to be coupled to a third antenna array; and

a control unit coupled between the transceiver circuit and the third antenna array,

wherein the control unit is configured to switch the third antenna array between non-directional or omnidirectional for the first transmission beam and directional for the second transmission beam.

17. A method for beamforming, the method comprising:

generating a control signal and a data signal;

converting the control signal to a first frequency of a first radio carrier;

forming a first transmission beam having a first beam width based on the converted control signal;

converting the data signal to a second frequency of a second radio carrier; and

forming a second transmission beam having a second beam width based on the converted data signal,

wherein the first frequency is lower than the second frequency, and

wherein the first beam width is broader than the second beam width.

18. The method of claim 17, comprising:

forming the first transmission beam as a non-directional beam or an omni-directional beam; and

forming the second transmission beam as a directional beam.

19. A computer readable non-transitory medium on which computer instructions are stored which when executed by a computer, cause the computer to perform the method of one of claims 17 to 18.

20. A beamforming device, comprising:

means for generating a control signal and a data signal;

means for converting the control signal to a first frequency of a first radio carrier;

means for forming a first transmission beam having a first beam width based on the converted control signal;

means for converting the data signal to a second frequency of a second radio carrier; and

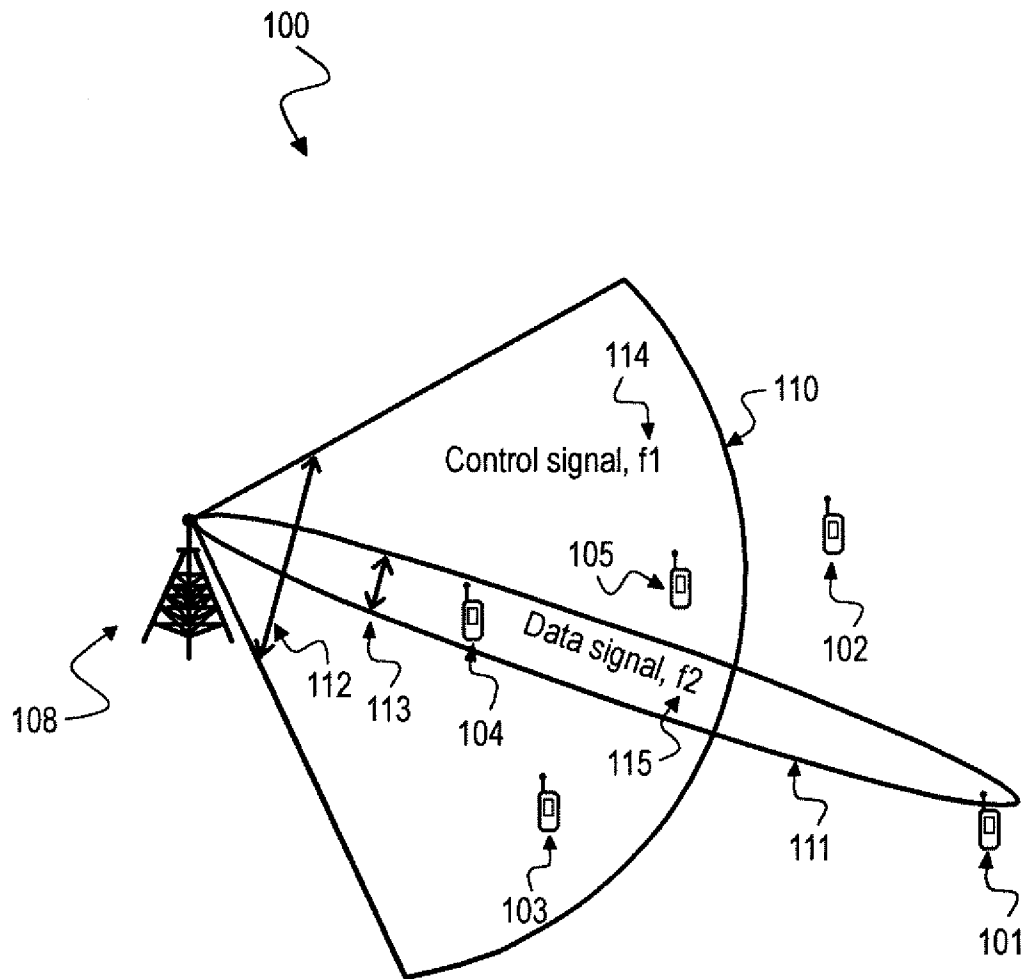
means for forming a second transmission beam having a second beam width based on the converted data signal,

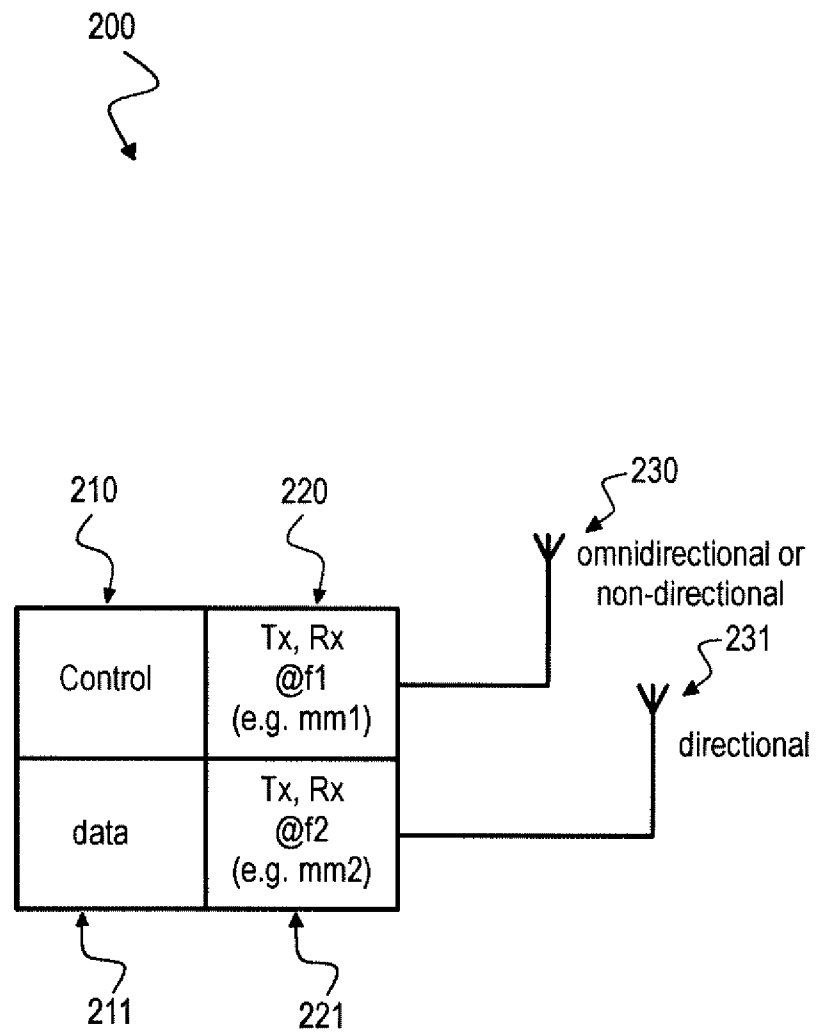
wherein the first frequency is lower than the second frequency, and

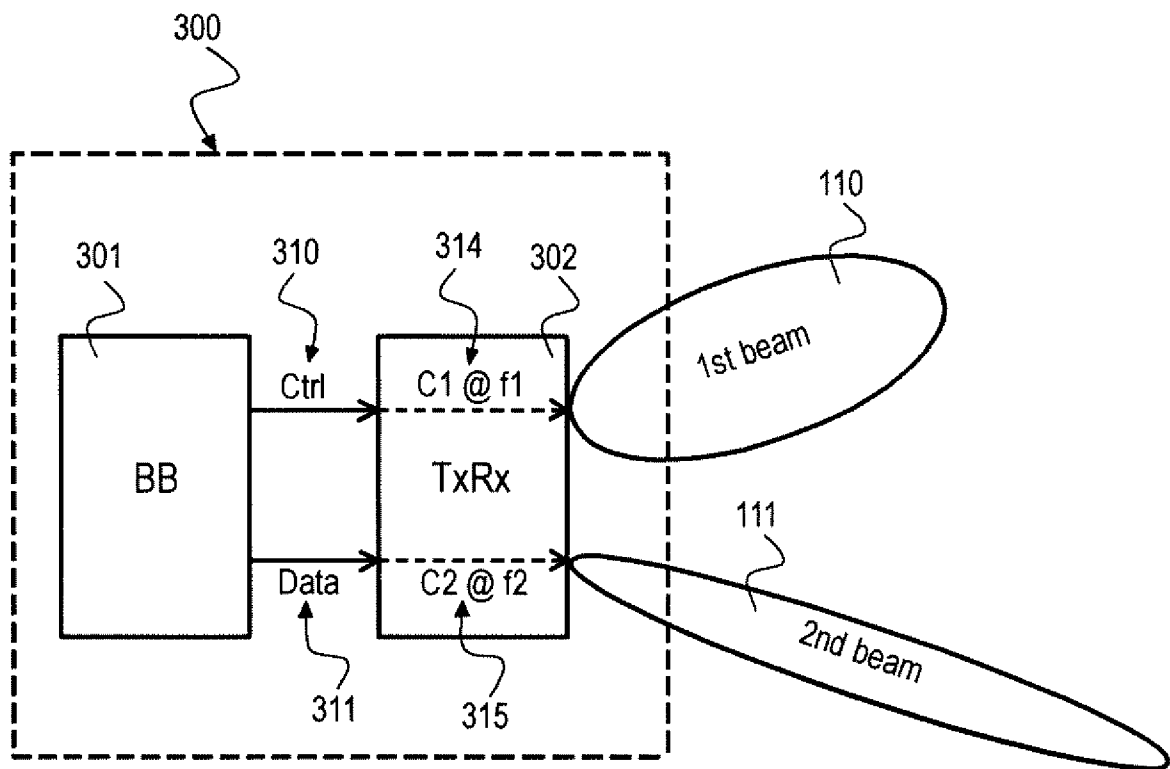
wherein the first beam width is broader than the second beam width.

21. The beamforming device of claim 20, comprising:
means for forming the first transmission beam as a non-directional beam or an omni-directional beam; and
means for forming the second transmission beam as a directional beam.
22. A beamforming circuit, comprising:
a baseband circuit configured to provide a plurality of control signals and a plurality of data signals; and
a transceiver circuit configured to:
convert each control signal to a frequency of a first radio carrier assigned to the control signal,
form for each converted control signal a first transmission beam having a first beam width,
convert each data signal to a frequency of a second radio carrier assigned to the data signal, and
form for each converted data signal a second transmission beam having a second beam width,
wherein for each control signal and data signal the frequency of the first radio carrier is lower than the frequency of the second radio carrier and the first beam width is broader than the second beam width.
23. The beamforming circuit of claim 22,
wherein the transceiver circuit is configured to adjust for each control signal and data signal the frequency of the first radio carrier, the frequency of the second radio carrier (315), the first beam width and the second beam width in order to form the first transmission beam and the second transmission beam having approximately a same range.

24. A beamforming system, comprising:
a baseband subsystem configured to provide a control signal and a data signal; and
a transceiver subsystem configured to:
convert the control signal to a first frequency of a first radio carrier,
form a first transmission beam having a first beam width based on the converted control signal,
convert the data signal to a second frequency of a second radio carrier, and
form a second transmission beam having a second beam width based on the converted data signal,
wherein the first frequency is lower than the second frequency and the first beam width is broader than the second beam width.
25. The beamforming system of claim 24,
wherein the transceiver subsystem is configured to form the first transmission beam as a non-directional beam or an omni-directional beam and to form the second transmission beam as a directional beam.

**Fig. 1**

**Fig. 2**

**Fig. 3**

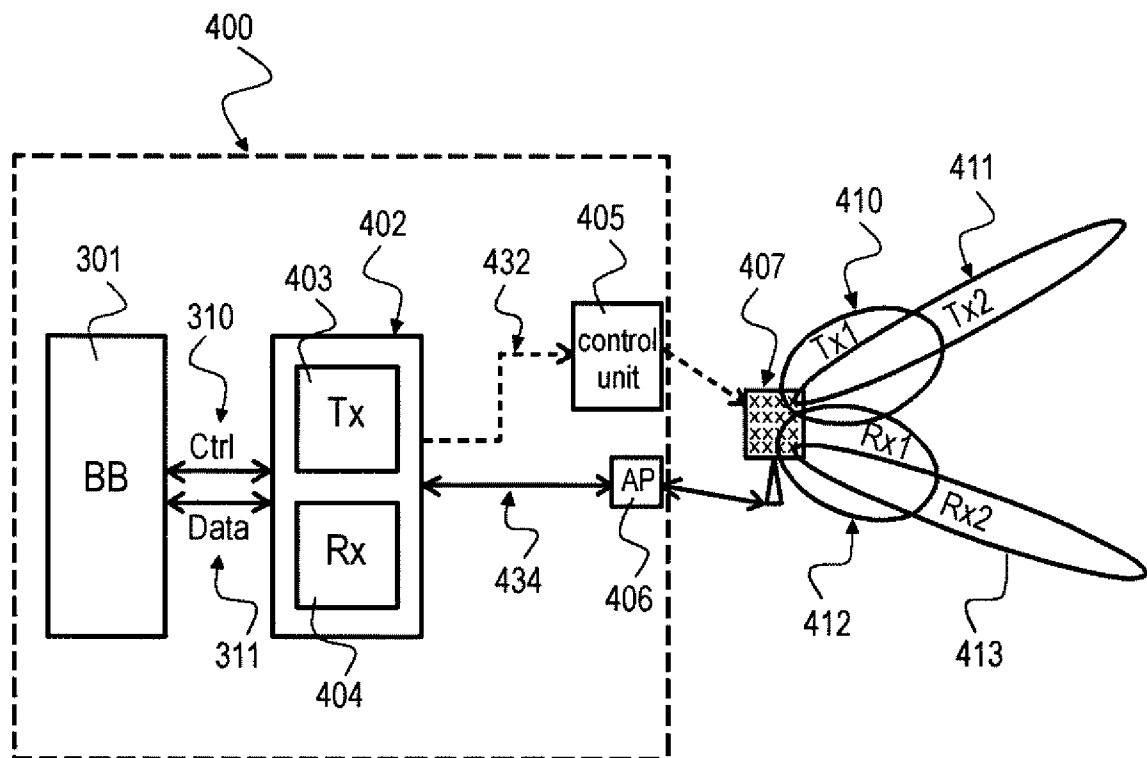
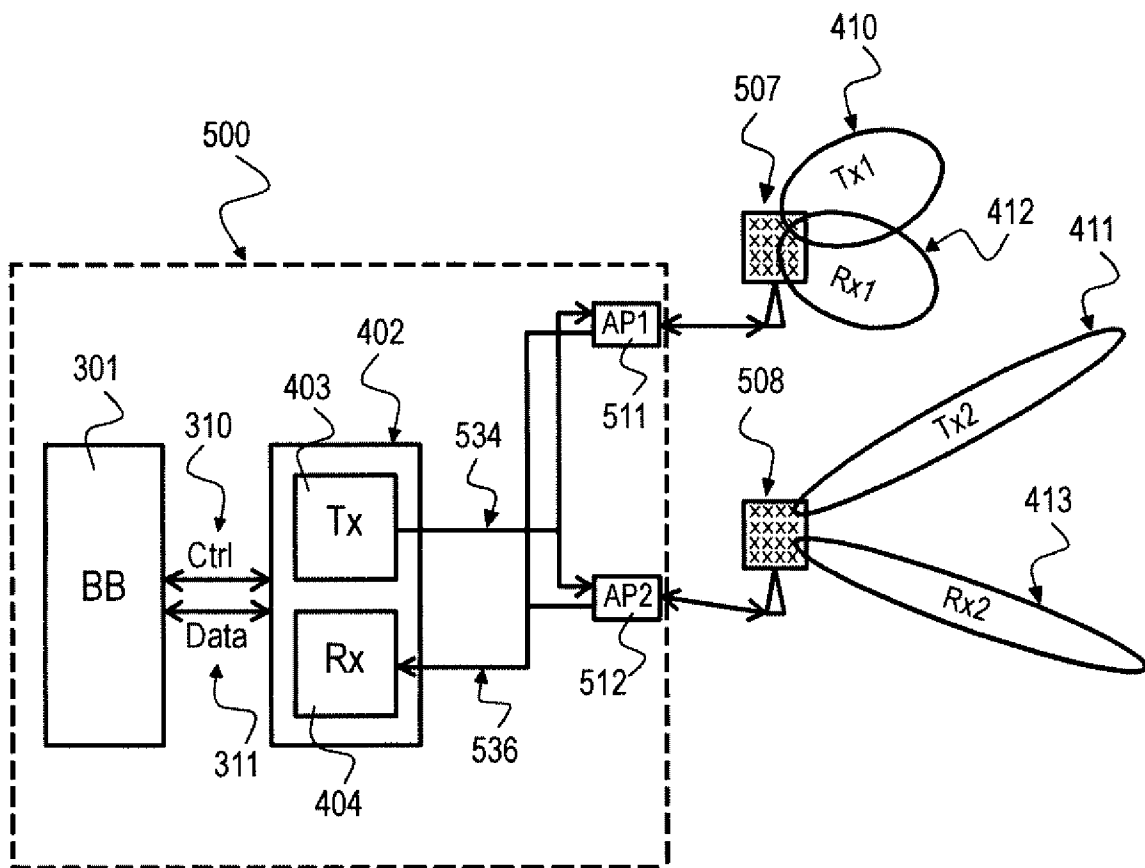


Fig. 4

**Fig. 5**

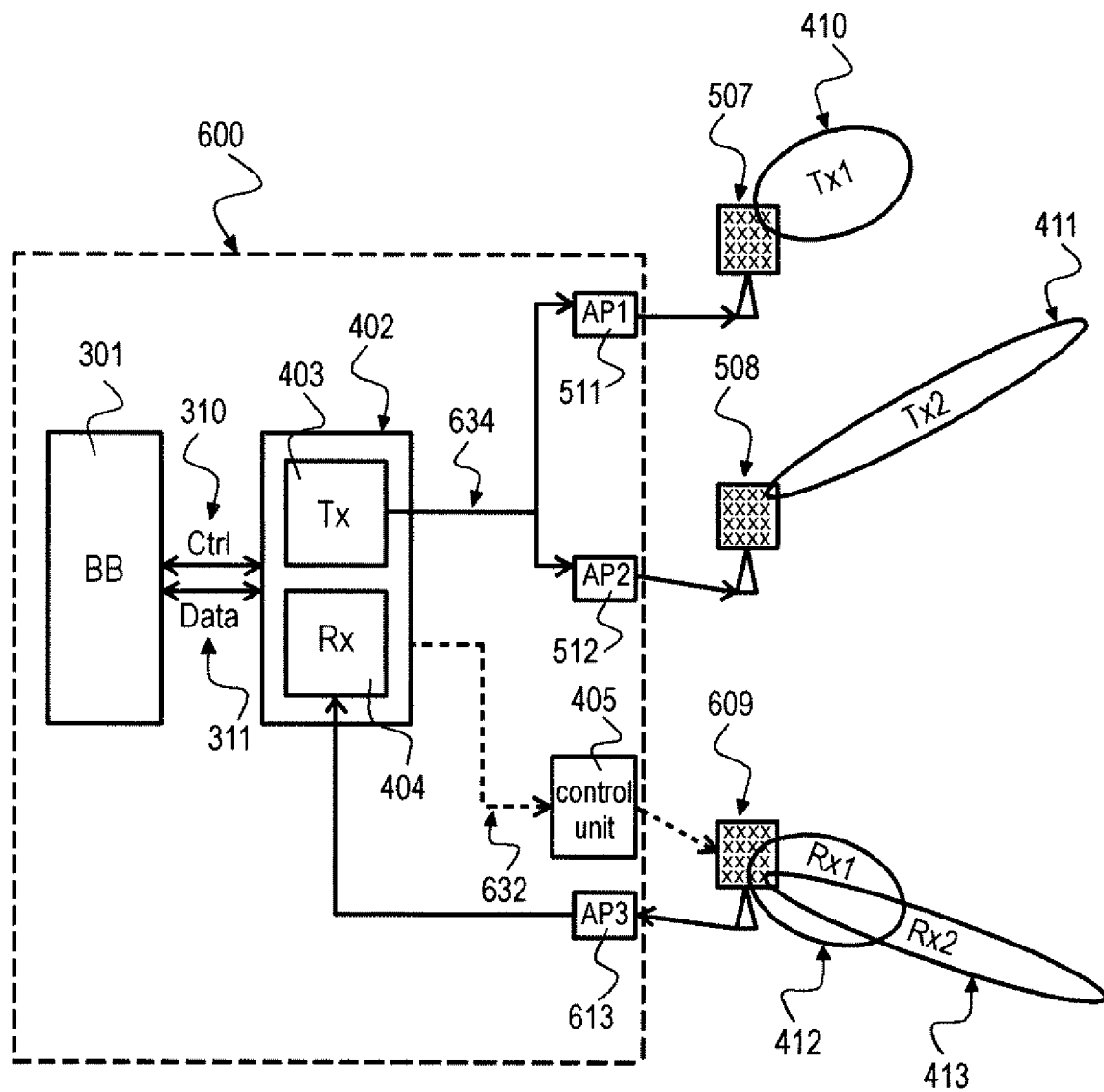


Fig. 6

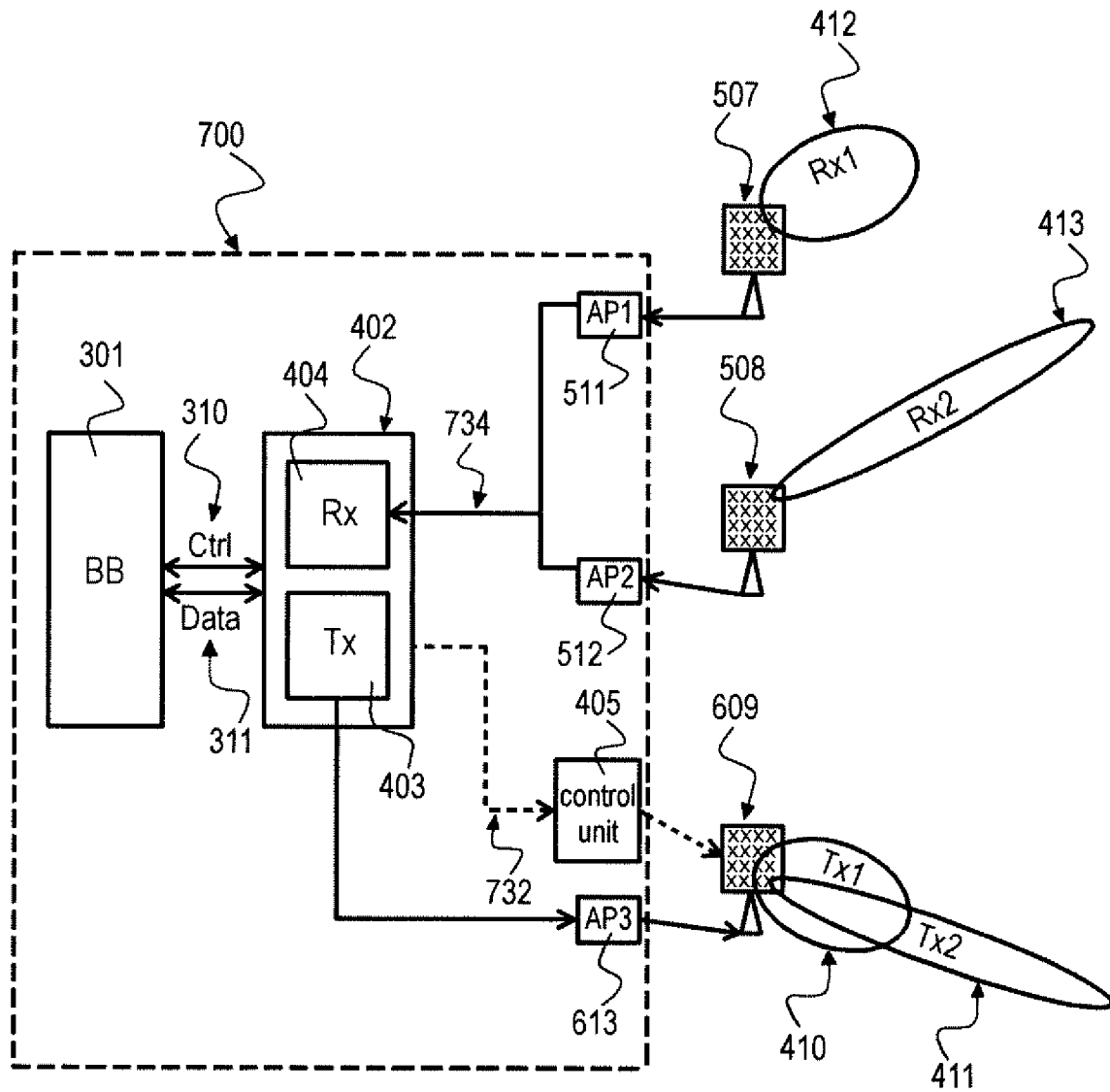
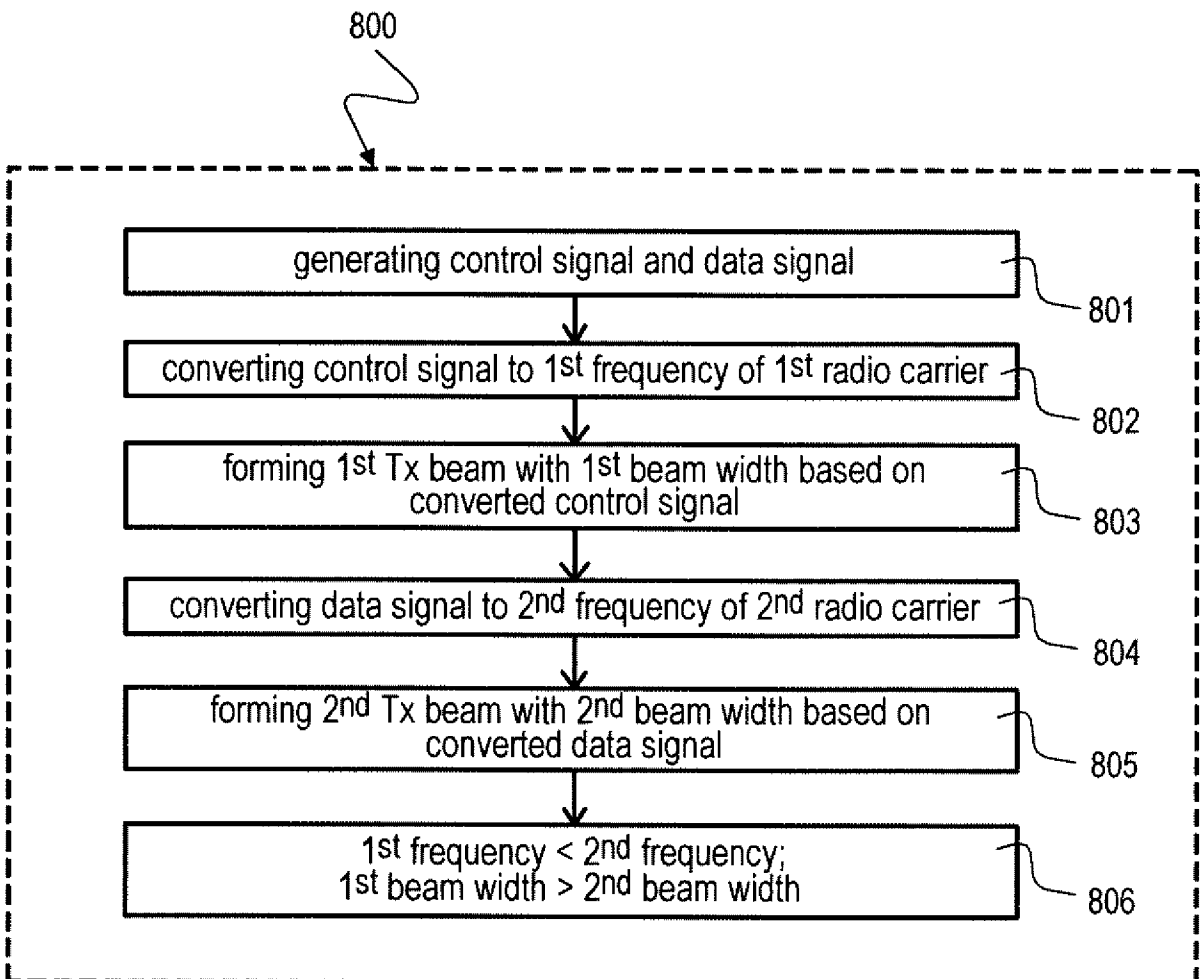


Fig. 7

**Fig. 8**

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/054789

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/06 H04W72/04
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)
H04B H04W

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)

EP0-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	US 2014/148107 A1 (MALTSEV ALEXANDER [RU] ET AL) 29 May 2014 (2014-05-29) paragraphs [0039] - [0050], [0060], [0199] - [0200]; figure 2 -----	1-3,5-8, 17-25
X	US 2011/182174 A1 (PI ZHOUYUE [US] ET AL) 28 July 2011 (2011-07-28) paragraphs [0005] - [0007], [0041] - [0044]; figures 3,4 -----	1,5-8, 17,19, 20,22,24

☐

Further documents are listed in the continuation of Box C.

☒

See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

2 May 2017

Date of mailing of the international search report

04/07/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Authorized officer

Sälzer, Thomas

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2017/054789

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-3, 5-8, 17-25

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-3, 5-8, 17-25

Transmitting control and data signals on different frequencies and with different beam widths

2. claim: 4

Choosing a frequency ratio

3. claims: 9-16

Generate transmission and reception beams with an antenna array

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2017/054789

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014148107 A1	29-05-2014	CN 105122664 A	02-12-2015
		EP 2926471 A1	07-10-2015
		US 2014148107 A1	29-05-2014
		WO 2014084912 A1	05-06-2014

US 2011182174 A1	28-07-2011	NONE	
