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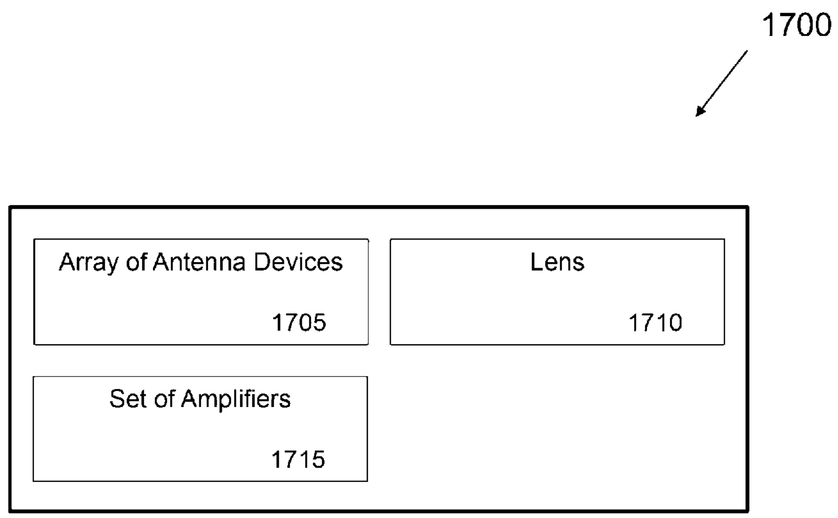

FIG. 17

(57) **Abstract:** Technologies are described for an antenna apparatus that includes an array of antenna devices that transmit or receive electromagnetic waves; a lens located in front of the array, where the lens causes at least some of the electromagnetic waves to pass through, reflect, or refract; and a set of amplifiers electrically coupled to the array of antenna devices, where each amplifier in the set of amplifiers is electrically coupled to at least one antenna device from the array of antenna devices, and where power gains of at least two signal paths formed by electrical couplings between least two antenna devices and at least two different amplifiers are unequal.

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WIRELESS COMMUNICATION ANTENNA

TECHNICAL FIELD

[0001] This document is directed generally to digital wireless communications.

BACKGROUND

[0002] Mobile telecommunication technologies are moving the world toward an increasingly connected and networked society. In comparison with the existing wireless networks, next generation systems and wireless communication techniques will need to support a much wider range of use-case characteristics and provide a more complex and sophisticated range of access requirements and flexibilities.

[0003] Long-Term Evolution (LTE) is a standard for wireless communication for mobile devices and data terminals developed by 3rd Generation Partnership Project (3GPP). LTE Advanced (LTE-A) is a wireless communication standard that enhances the LTE standard. The 5th generation of wireless system, known as 5G, advances the LTE and LTE-A wireless standards and is committed to supporting higher data-rates, large number of connections, ultra-low latency, high reliability and other emerging business needs.

SUMMARY

[0004] The antenna technology disclosed in this patent document is related to wireless communications and can solves the technical problem of uneven coverage power in different transmitting/receiving angle by antenna arrays. The disclosed antenna technology can also reduce the hardware cost.

[0005] An example antenna apparatus includes an array of antenna devices that transmit or receive electromagnetic waves; a lens located in front of the array, where the lens causes at least some of the electromagnetic waves to pass through, reflect, or refract; and a set of amplifiers electrically coupled to the array of antenna devices, where each amplifier in the set of amplifiers is electrically coupled to at least one antenna device from the array of antenna devices, and where power gains of at least two signal paths formed by electrical couplings between least two antenna devices and at least two different amplifiers are unequal.

[0006] In some embodiments, the set of amplifiers includes at least two amplifiers that have preset amplification factors. In some embodiments, the at least two amplifiers includes a first amplifier and a second amplifier, the first amplifier has a higher preset amplification factor than that of the second amplifier, the first amplifier is electrically coupled to a first antenna device located towards an edge of the array of antenna devices, the edge of the array of antenna devices is located away from a center area of the array of antenna devices, and the second amplifier is electrically coupled to a second antenna device located towards the center area of the array of antenna devices. In some embodiments, the set of amplifiers include variable gain amplifiers that have tunable amplification factors.

[0007] In some embodiments, the set of amplifiers have a same amplification factor. In some embodiments, the set of amplifiers include a first amplifier that is electrically coupled to N_1 antenna devices located towards an edge of the array of antenna devices and away from a center area of the array of antenna devices, the set of amplifiers includes a second amplifier that is electrically coupled to N_2 antenna devices located towards the center area of the array of antenna devices, and N_1 and N_2 are both integers greater than or equal to 1, and N_1 is less than N_2. In some embodiments, the set of amplifiers include at least one amplifier that is switchably and electrically couplable to different sets of antenna devices via a switch, and each of the sets of antenna devices includes at least one antenna devices.

[0008] In some embodiments, the antenna apparatus further comprises a set of phase shifter devices that are electrically coupled to the array of antenna devices or to the set of amplifiers. In some embodiments, an output of each phase shifter device is electrically coupled to an input of a different amplifier of the set of amplifiers. In some embodiments, at least one amplifier is electrically coupled to at least one antenna device via at least one phase shifter device. In some embodiments, an amplifier is electrically coupled to different antenna devices via one phase-shifter. In some embodiments, an amplifier is electrically coupled to a first antenna device and a second antenna device via a first phase-shifter device and a second phase-shifter device, respectively. In some embodiments, the at least one amplifier is electrically coupled to the at least one antenna device via at least two phase shifter devices.

[0009] In some embodiments, the array of antenna devices are located on one or more imaginary planes that extend along a first direction and a second direction, the lens is located on another imaginary plane that is different from the one or more imaginary planes, and the lens extends along the first direction, the second direction, and a third direction perpendicular to the first direction and the second direction. In some embodiments, the antenna apparatus further comprises a transmit or receive signal processing chain that is configured to transmit or receive signals by selecting at least some of the array of antenna devices and by using at least some of the set of amplifiers. In some embodiments, the antenna apparatus further comprises a transmit or receive signal processing chain that is configured to transmit or receive signals by selecting all of the array of antenna devices and by using the set of amplifiers. In some embodiments, the lens includes a meta-surface.

[0010] In yet another exemplary aspect, the above-described methods are embodied in the form of processor-executable code and stored in a non-transitory computer-readable storage medium. The code included in the computer readable storage medium when executed by a processor, causes the processor to implement the methods described in this patent document.

[0011] In yet another exemplary embodiment, a device that is configured or operable to perform the above-described methods is disclosed.

[0012] The above and other aspects and their implementations are described in greater detail in the drawings, the descriptions, and the claims.

BRIEF DESCRIPTION OF THE DRAWING

[0013] FIGS. 1A and 1B respectively show an example beamforming gain of a lens antenna and a beamforming gain of a traditional phased array.

[0014] FIGS. 2A-2C show three example feed arrays.

[0015] FIG. 3A-3D show four example types of cross-sections of the lens.

[0016] FIG. 4 shows an example of lens with cavities, where six groups of radially distributed cavities are set in the circular lens.

[0017] FIG. 5 shows an example schematic diagram of a reconfigurable intelligent surface.

[0018] FIGS. 6-8 show examples schematic diagrams of antennas.

[0019] FIG. 9 shows an example schematic diagram of the cascaded connection of the power divider between the amplifier and the antenna units.

[0020] FIGS. 10-14 show additional examples schematic diagrams of antennas.

[0021] FIG. 15 shows an exemplary block diagram of a hardware platform that may be a part of a network device or a communication device.

[0022] FIG. 16 shows an example of wireless communication including a base station (BS) and user equipment (UE) based on some implementations of the disclosed technology.

[0023] FIG. 17 shows an example block diagram of an example antenna apparatus.

DETAILED DESCRIPTION

[0024] Lens antenna is a new type of wireless signal transmitting device, which consists of a small-scale feed array and a lens with a large aperture. Since fewer feed antennas are used for signal transmission, the circuit design inside can be simplified and the power consumption and hardware costs can also be reduced. In millimeter-wave band, lens antenna can achieve very high beamforming gain with a lower cost compared with traditional phased array.

[0025] FIGS. 1A and 1B respectively show an example beamforming gain of a lens antenna and a beamforming gain of a traditional phased array. As shown in FIGS. 1A-1B, the respective beamforming gains of a lens antenna and a traditional phased array are compared in different transmitting angles by array simulation. The 5 beams in FIG. 1A are respectively obtained by a lens antenna with an aperture of 16 wavelengths fed respectively by 5 antenna groups. Each of the 5 antenna groups consists of 4 rows and 4 columns antennas working at 30 GHz. In FIG. 1B, the 5 beams are transmitted by an array with 4 rows and 4 columns antennas directly. The maximum beamforming gain can reach about 14 dB with a lens antenna compared with the phased array. Higher gain can be achieved if a lens with a larger aperture is used. In order to obtain the same beamforming gain, the traditional phased array needs to increase the number of antennas to form a larger aperture with will greatly increase the hardware cost.

[0026] Although the lens antenna is able to achieve higher beamforming gain, there are gain differences among the transmitting angles. As shown in FIG. 1A, the beam at the normal direction of the lens plane (90-degree) has the largest gain and the gain decrease gradually when the transmitting angle deviates from the normal direction. When the beam direction approaching 60-degree, a 10 dB gain drop is observed. This phenomenon is due to the fact the beams towards different angles are transmitted by antennas at different position which results in different incident angle to the lens. Different incident angle means different effective aperture and hence leads to different beamforming gain.

[0027] If such lens antennas are utilized for wireless communications, the end users may experience communication signal fluctuation or even interruption during their movement within the service area of the base station. This defect can hinder the commercial application of lens antenna in wireless communications. To address at least these technical problems, a new design is proposed in this patent document.

[0028] The example headings for the various sections below are used to facilitate the understanding of the disclosed subject matter and do not limit the scope of the claimed subject matter in any way. Accordingly, one or more features of one example section can be combined with one or more features of another example section.

[0029] **<u>I. Example Antenna Technology</u>**

[0030] This patent document proposes an example antenna apparatus for transmitting and receiving wireless signals, which including at least a feeding array, a lens and an amplifier module. The lens may be located in front of and faces the feeding array. Thus, the feeding array and the lens can be respectively three-dimensional objects that can extend along two parallel planes that include a first plane for a feeding array and a second plane for the lens. The second plane includes the projections of the feeding array and the lens, where the projections are at least partially overlapped. The amplifier module may include of a set of amplifiers connected to the feed array, which amplifies the input and output signal of the feed array. The modules/devices of the antenna apparatus are introduced as follows.

[0031] **<u>I.A. Example Feed Array</u>**

[0032] The feed array may include at least one antenna unit (also known as an antenna device). An antenna unit (or an antenna device) is a component of the feed array that can transmit a wireless signal independently and it can be a microstrip antenna, a slot antenna, a dielectric antenna, a horn antenna, etc. FIGS. 2A-2C show three example feed arrays, where each feed array includes multiple antenna units. In FIG. 2A, the antenna units are placed along the x-axis, and in FIGS. 2B-2C, the antenna units are placed along x-y plane(s).

[0033] Multiple antenna units can be arranged to form an antenna array that can be referred to as the feed array. For example, the antenna units can lie in the same direction to form a linear array, as shown in FIG. 2A. The antenna units can also lie in a same plane to form a circular or rectangular array, as shown in FIG. 2B. In addition, the antenna unit can be deployed on a curved surface to form a curved array and the spherical array as shown in FIG. 2C can be a typical example. The apparatus proposed can either apply all the antenna units or select only a part of the antenna units for signal transmission. The planar circular or rectangle arrays can also be piled up to form a three dimensional feed array in the proposed apparatus.

[0034] The apparatus proposed can perform signal transmission by applying or selecting all the antenna units or by selecting only a part of the antenna units. By choosing or selecting different antenna unit or set of antenna units for signal transmission, the apparatus proposed can generate beams towards different directions. When multiple antenna units or sets of antenna units are chosen for transmission, multiple beams can be generated by the apparatus. An antenna unit or a set of antenna units near the center of the feed array may be responsible for generating a beam near the normal direction of the lens while those near the edge of the feed array may be designated for generating beams in large oblique angles. In a lens antenna, a beam may be switched by choosing or selecting another set of antenna units.

[0035] **<u>II.B. Example Lens</u>**

[0036] A portion of a lens (e.g., a vertical cross-section of a lens) may be located in a plane that may be parallel to a plane along which the feed array extends. The lens in the proposed apparatus can create a reflection or a refraction of the incoming signal so as to steer the signal to a desired transmission direction. When it allows the signal to pass, the lens may have a large transmission coefficient while a large reflection coefficient may be required if it is used for signal reflection. A lens may include an optical lens or a meta-surface.

[0037] In order to shape the wave-front of the impinging signal, the width of the cross-section of the lens is designed to vary along the second direction, where the cross-section of the lens is parallel to the first direction while the second direction is perpendicular to the first direction and the width is measured along the first direction. FIG. 3A-3D show four example types of cross-sections of the lens, where the horizontal and vertical arrows indicate the first and the second directions, respectively. In FIGS. 3A-3D, the feed array extends along a plane that comprises the second direction, can be located to the left or the right of the lens, and faces the lens. FIGS. 3A-3D are side views of the example lens. In the front view, the lens can be in circular or rectangle shapes, or another projection shape. In some cases, more complicated lens shape can be designed in order to manipulate the impinging electromagnetic wave precisely. The design of the lens shape can provide different path length at different part of the lens for the incoming signals so that the phases of the signals passing different parts of the lens can be changed and such changes can finally lead to in-phase superposition of the signals in the desired transmission direction.

[0038] In some embodiments, the lens is made of uniform dielectric material, such as glass, acrylic, polyester resin, polyepoxy resin, and minerals such as fluorite or quartz. In order to shape the wave-front of the impinging signal, there is at least one preset cavity in the lens. Drilling holes in the lens can be one way to generate cavities in a uniform lens. In some cases, the cavities can also be filled with other materials with a dielectric constant differing from the lens. A technical benefit of having cavities filled with other materials is that the cavity can be filed with a material having a different dielectric property (e.g., higher permittivity) than the material of the lens so that the lens can be made thinner than it otherwise would. By presetting the cavities in lens, the effective permittivity varies in different part of the lens, which changes the phase of the signal passing through differently. By designing the location of the cavities in the lens, a desired beamforming can be obtained. By presetting cavities, the surface of the lens can be designed to be flat, which is more convenient for assembling, packaging and transportation.

[0039] FIG. 4 shows an example of lens with cavities, where six groups of radially distributed cavities are set in the circular lens. Such cavities can make the permittivity of the lens vary gradually from the center to the edge. By drilling holes in the lens, the weight of the lens can also be reduced, which also benefits the on-site installation of the apparatus.

[0040] In some other embodiments, the lens is composed of heterogeneous dielectric materials and the cross-section of the lens has the same width along the second direction. Due to the heterogeneous compositions, the effective permittivity varies in the lens. In one case, the permittivity of the lens varies linearly for the center to the edge. In other cases, in order to obtain higher beamforming gain, the permittivity does not change linearly with the position but can satisfy a high-order function, such as a parabolic function.

[0041] In some other embodiments, a meta-surface is utilized as a lens. A meta-surface is a passive array consisting of a group of electromagnetic units. Each electromagnetic unit is able to manipulate the phase, the amplitude, the polarization or the frequency of the impinging electromagnetic wave. The electromagnetic units form planar or curved reflection or transmission array on the meta-surface. In some embodiments, the electromagnetic unit is in the size of sub-wavelength with specially designed shape. In some cases, the electromagnetic unit has layered structure, which consist of a least a substrate layer and a patch layer. The substrate layer is filled with dielectric, such as polyepoxy resin. The patch layer contains at least one metallic patch. The shape of patch can be a rectangle, a cross (e.g., Jerusalem cross), a split ring or other shape that can induce desired electromagnetic resonance. The electromagnetic unit can reflect or transmit the incoming signal. In some cases, there is also a metallic ground layer in the unit to assist the reflection of the incoming signal. In some other cases, the electromagnetic unit can change its effective impedance on demand and the meta-surface consists of such electromagnetic units is called a reconfigurable intelligent surface. The change of the effective impedance is controlled by the embedded circuit. For example, a phase-shift-type electromagnetic unit can change the phase of the incident signal. FIG. 5 shows a type of reconfigurable intelligent surface, which is a planar array with 64 electromagnetic units. There is a circuit with a positive intrinsic negative (PIN) diode embedded in each of the electromagnetic unit. The state of the circuit is controlled by the smart controller. If this reconfigurable intelligent surface is a phase-shift-type surface, the specific amount of phase change to the electromagnetic wave impinging upon each electromagnetic unit is controlled by the input signal from the smart controller. In some embodiments, the smart controller may include a processor and a memory that includes instructions that cause the processor to generate the input signal to control a specific amount of phase change to the electromagnetic wave impinging upon each electromagnetic unit.

[0042] I.C. Example Amplifier Module/Device

[0043] The amplifier module may include at least one amplifier. Each amplifier in the amplifier module is used for amplifying the signal to be transmitted. The amplifier module can be connected with or electrically coupled to the feed array in some embodiments.

[0044] In some embodiments, the number of amplifiers in the amplifier module can equal the number of antenna units in the feed array. Furthermore, each of the amplifiers can be connected with only one antenna unit. At least one of these amplifiers has a different amplification factor (e.g., different preset amplification factor) than another amplifier. In some embodiments, at least two amplifiers have a same preset amplification factor. The amplification factor can determine how much bigger the output signal is than the input signal with the amplifier, the amplification factor can also be known as power gain. In one case, the amplifiers connected with the antenna units locating in the central region of the feed array have lower amplification factors than those connected with the antenna units at the edge of the feed array. One example is shown in FIG. 6, where the feed array is composed of six antenna units. The feed array is coaxial with the lens and each antenna unit is connected with an amplifier. The size of the amplifier indicates the ability of amplification in FIG. 6, so that smaller amplifier icons associated with the middle two amplifier indicates a smaller amplifier compared to larger amplifier icons associated with the upper-most and lower-most amplifiers indicates a larger amplification factor compared to the other amplifier icons. Since the cost of the amplifier usually increases with the increase of the amplification factor, if the same type of amplifier is adopted, the amplification factor needs to be decided according to the maximum transmission power requirement, which will increase the hardware cost of the signal transmitting device. If non-uniform amplifiers are utilized according to the location of the antenna unit they connect, hardware cost can be reduced without affecting the coverage of the transmitting signals. In some embodiments, non-uniform amplifiers are electrically connected to the feed array.

[0045] In another embodiment, the amplifier module is composed of variable gain amplifiers (VGA) that may have a tunable amplification factor rather than a fixed amplification factor. Furthermore, at least one of the amplifiers has a different preset amplification factor than at least one other amplifier. As mentioned above, the antenna units near the edge of the feed array, which is responsible for transmitting the signals towards large oblique angle, need greater power to meet the specified gain requirement, hence the amplifier connected to the antenna unit near the edge or in the edge area of the array requires a larger amplification factor. As shown in FIG. 7, the variable gain amplifiers can be used and the amplification factor of the amplifiers connected to the antenna unit at the edge can be set to be higher than those connected with the antennas at central area. Such design can help reduce the power consumption without affecting the coverage range.

[0046] In another embodiment, the amplifiers in the amplifier module have the same amplification factor but at least one amplifier is connected to more antenna units than another amplifier. The amplifier can be connected to more than one antenna unit by means of power dividers. For example, an amplifier can connect two antenna unit with a two-way power divider device. In one case, the amplifier configured to connect the antenna unit in the central area of the feed array can connect more antenna units than the amplifier configured to connect the antenna units at the edge area of the feed array. As shown in FIG. 8, the amplifier connects two antenna unit in the central area while only one antenna unit is connected for the edge amplifiers. Consequently, more power dividers are applied near the central area of the feed array. In some cases, due to the limit of the number of paths a power divider can provide, cascaded connections of power dividers are required between the amplifier and the antenna units and an example is shown in FIG. 9. FIG. 9 shows an example schematic diagram of the cascaded connection of the power divider between the amplifier and the antenna units. Since the central antenna units require lower power for the same signal coverage range, it is reasonable for an amplifier to connect more antenna units at the same time. Such design helps reduce the number of the amplifiers in the amplifier module and hence lower the hardware cost.

[0047] In another embodiment, the amplifier module may also include switches with which the connections between the amplifiers and the antenna units can be determined or configured. Since the transmission of the wireless signals may only need a part of the antenna units in the feed array, if a full connection between the amplifier module and the feed array, there are idle amplifiers in each transmission. Hence, it may be better to reduce the idle amplifiers to lower the hardware cost in some embodiments. This can be accomplished by introducing switches between the amplifiers and the antenna units. As shown in FIG. 10, the central amplifier is connected to two groups of antenna units via a single-pole double-throw switch. With the switch, the output signal from the amplifier can be fed to either antenna units group dynamically, where each antenna units group includes at least one antenna unit. Compared with FIG. 8, the example design in FIG. 10 removes one more amplifier in the amplifier module. Theoretically, the two antenna units at both edge of the feed array in FIG.

10 can also share a same amplifier via a switch in order to further reduce the number of the amplifiers. However, the length of the connection line can also be a critical parameter in the hardware design. Longer connection line gives rise to larger power loss and hence it may not be a good choice for two electronic components that are far apart to share an amplifier.

[0048] In FIGS. 8-10, a first amplifier is connected to N_1 antennas, and a second amplifier is connected to N_2 antennas, where N_1 and N_2 are integers greater than or equal to 1, and where $N_1 > N_2$. The signal input into these two amplifiers from the radio-frequency chain can be of the same power, and hence, each antenna connected to the first amplifier can receive $1/N_1$ the input power, and each antenna connected to the second amplifier receives $1/N_2$ the input power. In this example, $1/N_1$ is different from or is not equal to $1/N_2$.

[0049] Since the larger the amplification factor, the higher the cost of the amplifier, an amplifier with high gain can also be replaced by two or more cascaded connected amplifier with lower gain and lower cost. Hence cascaded connection between amplifiers can be used in the amplifier module.

[0050] In some embodiments, the amplifier module may include amplifiers with different amplification factors, where the amplifiers with different amplification factors are electrically coupled to different number of antennas in the array of antenna device. Such a design can further help balance the beamforming gain at different transmission directions by ensuring that the signals input to the antennas in the edge area of the array of antenna device have higher power gain then those input to the antennas in the central area of the array of antenna device.

[0051] **<u>I.D. Example Phase Shifter Module/Device</u>**

[0052] The proposed apparatus can also include a phase shifter module. The phase shifter module contains at least one phase shifter device, which can be used for modifying the phase of the signal passing through.

[0053] In some embodiments, output of the phase shifters in the phase shifter module are connected to the input ports of the amplifiers in amplifier module for modifying the phase of the input signal to the amplifier module. An example is shown in FIG. 11. Such design offers a new degree of freedom for the beam steering with the proposed apparatus. In some cases, one phase shifter can connect more than one amplifier, which helps reduce the number of phase shifters and lower the hardware cost.

[0054] In some other embodiments, the phase shifters in the phase shifter module are connected to the output ports of the amplifiers in amplifier module for modifying the phase of the output signal from the amplifier module. An example is shown in FIG. 12. In some cases, one phase shifter can connect more than one amplifier, which helps reduce the number of phase shifters and lower the hardware cost. For example, in FIG. 12, an input of each phase shifter device is electrically coupled to an output of a different amplifier of the set of amplifiers, where the set of phase shifter devices includes a first phase shifter device that has an output that is electrically coupled to an input of one antenna device located towards an edge of the array of antenna devices and away from a center area of the array of antenna devices, and where the set of phase shifter devices includes a second phase shifter device that has an output that is electrically coupled to inputs of at least two antenna devices located towards the center area of the array of antenna devices.

[0055] In another embodiment, the phase shifters are connected to the input ports of the antenna units for modifying the phases of the transmitted signals from the antenna units. An example is shown in FIG. 13. For example, in FIG. 13, the set of phase shifter devices includes a first phase shifter device that has: an input that is electrically coupled to an output of one amplifier device, and an output that is electrically coupled to an input of a first antenna device located towards an edge of the array of antenna devices and away from a center area of the array of antenna devices; and the set of phase shifter devices includes at least two phase shifter devices that have: inputs that are electrically coupled to a same output of another amplifier device, and outputs that are electrically and correspondingly coupled to antenna devices located towards the center area of the array of antenna devices. In some cases, a phase shifter can connect more than one antenna unit in order to reduce the use of phase shifter. Furthermore, there can be cascaded connection between phase shifters in the phase shifter module, which can also help reduce the total number of phase shifter in the apparatus. An example is shown in FIG. 14. In the example in FIG. 14, a set of phase shifter devices includes a first phase shifter device that has an output that is electrically coupled to an input of a second phase shifter device, and an output of the second phase shifter device is electrically coupled to at least one antenna device.

[0056] The lens model in FIGS. 6-8 and FIGS. 10-13 are shown in the shape of an optical lens as an example, but meta-surfaces are also applicable for the lens.

[0057] **<u>I.E. Example Baseband Processing Module/Device</u>**

[0058] The proposed apparatus also includes a baseband processing module, which can be used for signal processing. As shown in FIG. 15, the baseband processing module 1525 may be included as part of a hardware platform 1500 that may be a part of a network device (e.g., base station) or a communication device (e.g., a user equipment (UE)). The hardware platform 1500 includes at least one processor 1510 and a memory 1505 having instructions stored thereupon. The instructions upon execution by the processor 1510 configure the hardware platform 1500 to perform operations associated with the baseband processing module 1525 and/or to perform the transmitting/receiving/signal processing operations described in the various embodiments described in this patent document. The transmitter 1515 transmits or sends information or data to another device using the antenna described in this patent document. For example, a network device transmitter can send a message to a user equipment. The receiver 1520 receives information or data transmitted or sent by another device using the antenna described in this patent document. For example, a user equipment can receive a message from a network device.

[0059] The information to be sent is firstly encoded and then modulated to the carrier frequency in the baseband processing module 1525. The modulated signals can be amplified in the amplifier module before the transmission by the feed array. By virtue of the channel reciprocity, the proposed apparatus can also be applied for receiving the wireless signals. In this case, the feed array can receive the wireless signals passing through the lens and pass these signals to the amplifier module for amplification. The amplified signals are finally processed by the baseband processing module, which at least includes demodulation and decoding.

[0060] The implementations as discussed above will apply to a wireless communication. FIG. 16 shows an example of a wireless communication system (e.g., a 5G or NR or 6G cellular network) that includes a base station 1620 and one or more user equipment (UE) 1611, 1612 and 1613. In some embodiments, the UEs access the BS (e.g., the network) using a communication link to the network (sometimes called uplink direction, as depicted by dashed arrows 1631, 1632, 1633), which then enables subsequent communication (e.g., shown in the direction from the network to the UEs, sometimes called downlink direction, shown by arrows 1641, 1642, 1643) from the BS to the UEs. In some embodiments, the BS send information to the UEs (sometimes called downlink direction, as depicted by arrows 1641, 1642, 1643), which then enables subsequent communication (e.g., shown in the direction from the UEs to the BS, sometimes called uplink direction, shown by dashed arrows 1631, 1632, 1633) from the UEs to the BS. The UE may be, for example, a smartphone, a tablet, a mobile computer, a machine to machine (M2M) device, an Internet of Things (IoT) device, and so on.

[0061] This patent document describes an example antenna apparatus that includes a feed array, a lens and an amplifier module/device. The lens may include a dielectric optical lens or meta-surfaces. The feed array can be a linear array, a two-dimensional planar array or a curved array. The amplifier module/device may include a set of amplifiers, where non-uniform amplifiers having different amplification factors may be used. Different amplifier can connect different number of antenna units in the feed array according to the part of the feed array that the amplifier connects. Such design can address the technical problem that the beamforming gain of the transmitting beams varies at different angle due to the variation of the effective aperture. Specific design schemes are provided to balance the performance and the cost of the apparatus.

[0062] The apparatus can also include a phase shifter module and a baseband module. The phase shifter module can be set at the input or output side of the amplifier module. The baseband module is for signal processing which is a common module in most wireless communication devices.

[0063] FIG. 17 shows an example block diagram of an example antenna apparatus 1700. The antenna apparatus 1700 includes an array of antenna devices 1705 that transmit or receive electromagnetic waves; a lens 1710 located in front of the array, where the lens causes at least some of the electromagnetic waves to pass through, reflect, or refract; and a set of amplifiers 1715 electrically coupled to the array of antenna devices, where each amplifier in the set of amplifiers is electrically coupled to at least one antenna device from the array of antenna devices, and where power gains of at least two signal paths formed by electrical couplings between least two antenna devices and at least two different amplifiers are unequal.

[0064] In some embodiments, the set of amplifiers includes at least two amplifiers that have preset amplification factors. In some embodiments, the at least two amplifiers includes a first amplifier and a second amplifier, the first amplifier has a higher preset amplification factor than that of the second amplifier, the first amplifier is electrically coupled to a first antenna device located towards an edge of the array of antenna devices, the edge of the array of antenna devices is located away from a center area of the array of antenna devices, and the second amplifier is electrically coupled to a second antenna device located towards the center area of the array of antenna devices. In some embodiments, the set of amplifiers include variable gain amplifiers that have tunable amplification factors.

[0065] In some embodiments, the set of amplifiers have a same amplification factor. In some embodiments, the set of amplifiers include a first amplifier that is electrically coupled to N_1 antenna devices located towards an edge of the array of antenna devices and away from a center area of the array of antenna devices, the set of amplifiers includes a second amplifier that is electrically coupled to N_2 antenna devices located towards the center area of the array of antenna devices, and N_1 and N_2 are both integers greater than or equal to 1, and N_1 is less than N_2. In some embodiments, the set of amplifiers include at least one amplifier that is switchably and electrically couplable to different sets of antenna devices via a switch, and each of the sets of antenna devices includes at least one antenna devices.

[0066] In some embodiments, the antenna apparatus further comprises a set of phase shifter devices that are electrically coupled to the array of antenna devices or to the set of amplifiers. In some embodiments, an output of each phase shifter device is electrically coupled to an input of a different amplifier of the set of amplifiers. In some embodiments, at least one amplifier is electrically coupled to at least one antenna device via at least one phase shifter device. In some embodiments, an amplifier is electrically coupled to different antenna devices via one phase-shifter. In some embodiments, an amplifier is electrically coupled to a first antenna device and a second antenna device via a first phase-shifter device and a second phase-shifter device, respectively. In some embodiments, the at least one amplifier is electrically coupled to the at least one antenna device via at least two phase shifter devices.

[0067] In some embodiments, the array of antenna devices are located on one or more imaginary planes that extend along a first direction and a second direction, the lens is located on another imaginary plane that is different from the one or more imaginary planes, and the lens extends along the first direction, the second direction, and a third direction perpendicular to the first direction and the second direction. In some embodiments, the antenna apparatus further comprises a transmit or receive signal processing chain that is configured to transmit or receive signals by selecting at least some of the array of antenna devices and by using at least some of the set of amplifiers. In some embodiments, the antenna apparatus further comprises a transmit or receive signal processing chain that is configured to transmit or receive signals by selecting all of the array of antenna devices and by using the set of amplifiers. In some embodiments, the lens includes a meta-surface.

[0068]

[0069] In some embodiments, the antenna apparatus described in this patent document includes a transmit or receive signal processing chain that is configured to transmit or receive signals using at least some of the array of antenna devices and at least some of the set of amplifiers. In some embodiments, the transmit or receive signal processing chain may include RF signal processor (e.g., processor 1510 in FIG. 15) or a baseband signal processor.

[0070] In this document the term "exemplary" is used to mean "an example of" and, unless otherwise stated, does not imply an ideal or a preferred embodiment.

[0071] Some of the embodiments described herein are described in the general context of methods or processes, which may be implemented in one embodiment by a computer program product, embodied in a computer-readable medium, including computer-executable instructions, such as program code, executed by computers in networked environments. A computer-readable medium may include removable and non-removable storage devices including, but not limited to, Read Only Memory (ROM), Random Access Memory (RAM), compact discs (CDs), digital versatile discs (DVD), etc. Therefore, the computer-readable media can include a non-transitory storage media. Generally, program modules may include routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types. Computer- or processor-executable instructions, associated data structures, and program modules represent examples of program code for executing steps of the methods disclosed herein. The particular sequence of such executable instructions or associated data structures represents examples of corresponding acts for implementing the functions described in such steps or processes.

[0072] Some of the disclosed embodiments can be implemented as devices or modules using hardware circuits, software, or combinations thereof. For example, a hardware circuit implementation can include discrete analog and/or digital components that are, for example, integrated as part of a printed circuit board. Alternatively, or additionally, the disclosed components or modules can be implemented as an Application Specific Integrated Circuit (ASIC) and/or as a Field Programmable Gate Array (FPGA) device. Some implementations may additionally or alternatively include a digital signal processor (DSP) that is a specialized microprocessor with an architecture optimized for the operational needs of digital signal processing associated with the disclosed functionalities of this application. Similarly, the various components or sub-components within each module may be implemented in software, hardware or firmware. The connectivity between the modules and/or components within the modules may be provided using any one of the connectivity methods and media that is known in the art, including, but not limited to, communications over the Internet, wired, or wireless networks using the appropriate protocols.

[0073] While this document contains many specifics, these should not be construed as limitations on the scope of an invention that is claimed or of what may be claimed, but rather as descriptions of features specific to particular embodiments. Certain features that are described in this document in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable sub-combination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a sub-combination or a variation of a sub-combination. Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results.

[0074] Only a few implementations and examples are described and other implementations, enhancements and variations can be made based on what is described and illustrated in this disclosure.

CLAIMS

What is claimed is:

1. An antenna apparatus, comprising:

an array of antenna devices that transmit or receive electromagnetic waves;

a lens located in front of the array,

wherein the lens causes at least some of the electromagnetic waves to pass through, reflect, or refract; and

a set of amplifiers electrically coupled to the array of antenna devices,

wherein each amplifier in the set of amplifiers is electrically coupled to at least one antenna device from the array of antenna devices, and

wherein power gains of at least two signal paths formed by electrical couplings between least two antenna devices and at least two different amplifiers are unequal.

2. The antenna apparatus of claim 1, wherein the set of amplifiers includes at least two amplifiers that have preset amplification factors.

3. The antenna apparatus of claim 2,

wherein the at least two amplifiers includes a first amplifier and a second amplifier,

wherein the first amplifier has a higher preset amplification factor than that of the second amplifier,

wherein the first amplifier is electrically coupled to a first antenna device located towards an edge of the array of antenna devices,

wherein the edge of the array of antenna devices is located away from a center area of the array of antenna devices, and

wherein the second amplifier is electrically coupled to a second antenna device located towards the center area of the array of antenna devices.

4. The antenna apparatus of claim 1, wherein the set of amplifiers include variable gain amplifiers that have tunable amplification factors.

5. The antenna apparatus of claim 1, wherein the set of amplifiers have a same amplification factor.

6. The antenna apparatus of claim 5,

wherein the set of amplifiers include a first amplifier that is electrically coupled to N_1 antenna devices located towards an edge of the array of antenna devices and away from a center area of the array of antenna devices,

wherein the set of amplifiers includes a second amplifier that is electrically coupled to N_2 antenna devices located towards the center area of the array of antenna devices, and

wherein N_1 and N_2 are both integers greater than or equal to 1, and N_1 is less than N_2.

7. The antenna apparatus of claim 1,

wherein the set of amplifiers include at least one amplifier that is switchably and electrically couplable to different sets of antenna devices via a switch, and

wherein each of the sets of antenna devices includes at least one antenna devices.

8. The antenna apparatus of claim 1, further comprising:

a set of phase shifter devices that are electrically coupled to the array of antenna devices or to the set of amplifiers.

9. The antenna apparatus of claim 8, wherein an output of each phase shifter device is electrically coupled to an input of a different amplifier of the set of amplifiers.

10. The antenna apparatus of claim 8, wherein at least one amplifier is electrically coupled to at least one antenna device via at least one phase shifter device.

11. The antenna apparatus of claim 10,

wherein an amplifier is electrically coupled to different antenna devices via one phase-shifter.

12. The antenna apparatus of claim 10,

wherein an amplifier is electrically coupled to a first antenna device and a second antenna device via a first phase-shifter device and a second phase-shifter device, respectively.

13. The antenna apparatus of claim 10,

wherein the at least one amplifier is electrically coupled to the at least one antenna device via at least two phase shifter devices.

14. The antenna apparatus of claim 1,

wherein the array of antenna devices are located on one or more imaginary planes that extend along a first direction and a second direction,

wherein the lens is located on another imaginary plane that is different from the one or more imaginary planes, and

wherein the lens extends along the first direction, the second direction, and a third direction perpendicular to the first direction and the second direction.

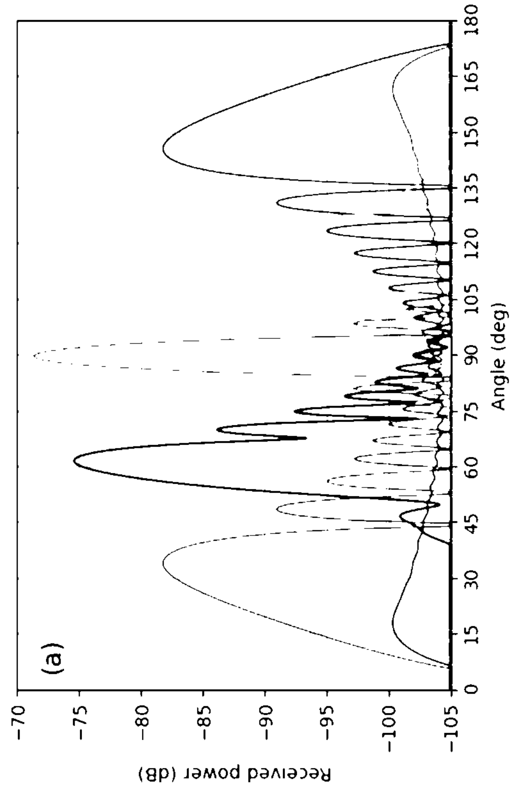
15. The antenna apparatus of claim 1, further comprising:

a transmit or receive signal processing chain that is configured to transmit or receive signals by selecting at least some of the array of antenna devices and by using at least some of the set of amplifiers.

16. The antenna apparatus of claim 1, further comprising:

a transmit or receive signal processing chain that is configured to transmit or receive signals by selecting all of the array of antenna devices and by using the set of amplifiers.

17. The antenna apparatus of any one of claims 1 to 16, wherein the lens includes a meta-surface.


(a)
Received power (dB)
Angle (deg)
−70
−75
−80
−85
−90
−95
−100
−105
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15
30
45
60
75
90
105
120
135
150
165
180

FIG. 1A

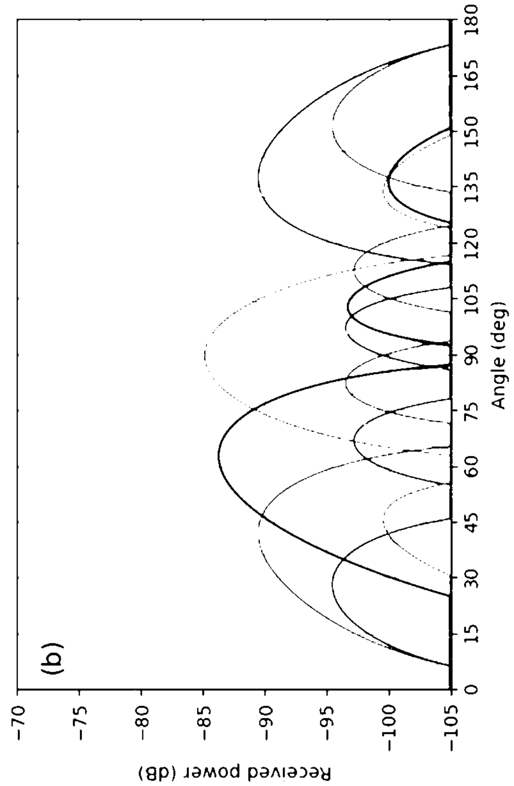
(b)
Received power (dB)
Angle (deg)
−70
−75
−80
−85
−90
−95
−100
−105
0
15
30
45
60
75
90
105
120
135
150
165
180

FIG. 1B

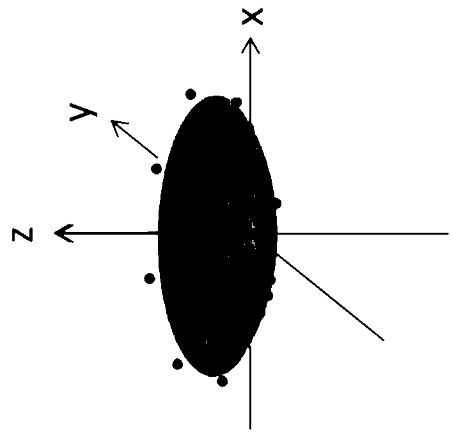

FIG. 2C

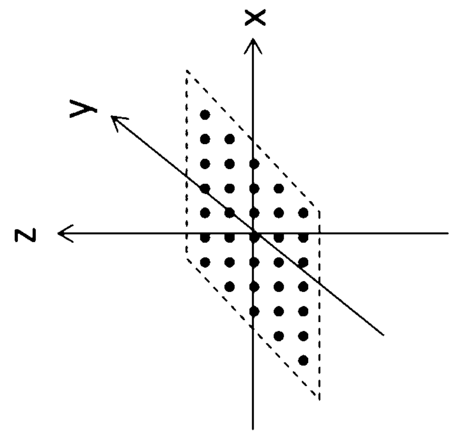

FIG. 2B

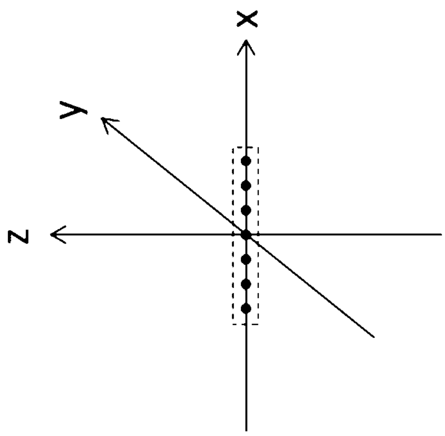

FIG. 2A

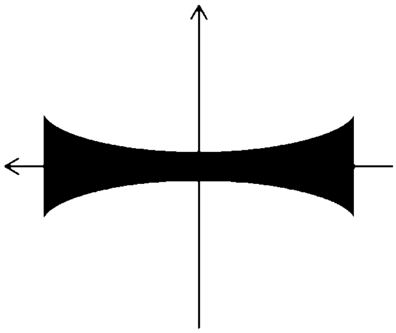
FIG. 3D

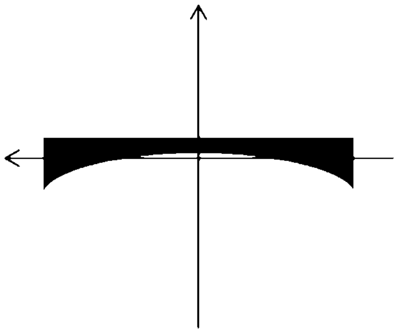
FIG. 3C

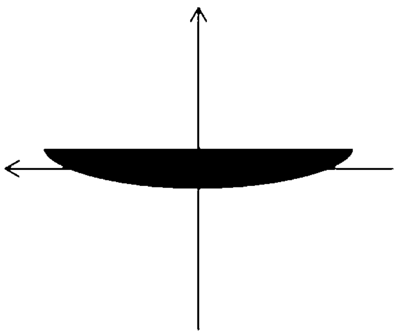
FIG. 3B

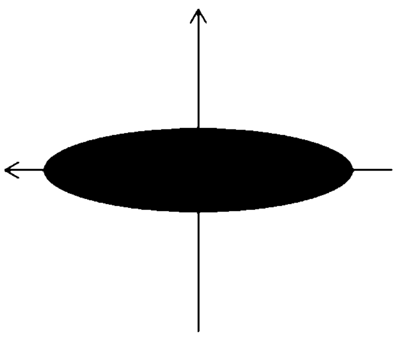
FIG. 3A

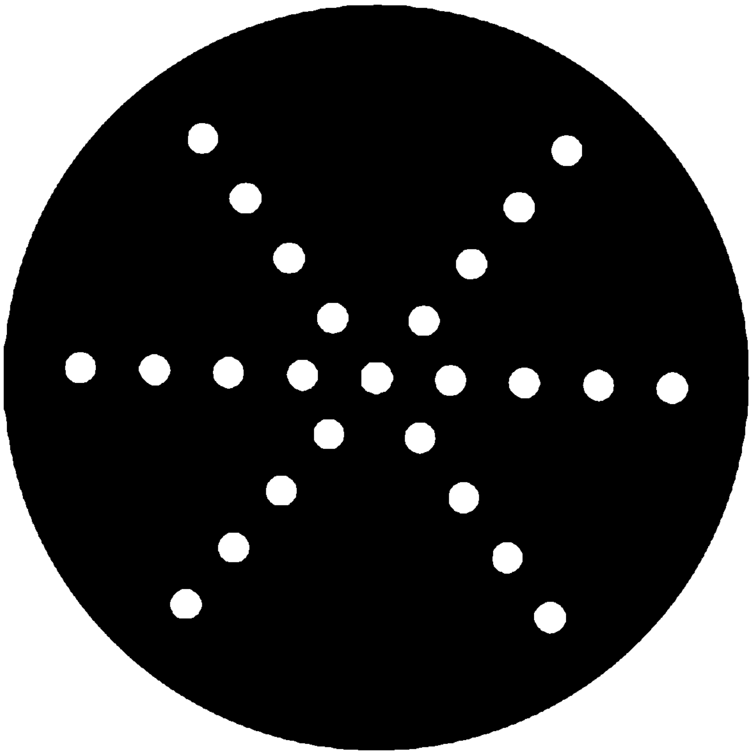

FIG. 4

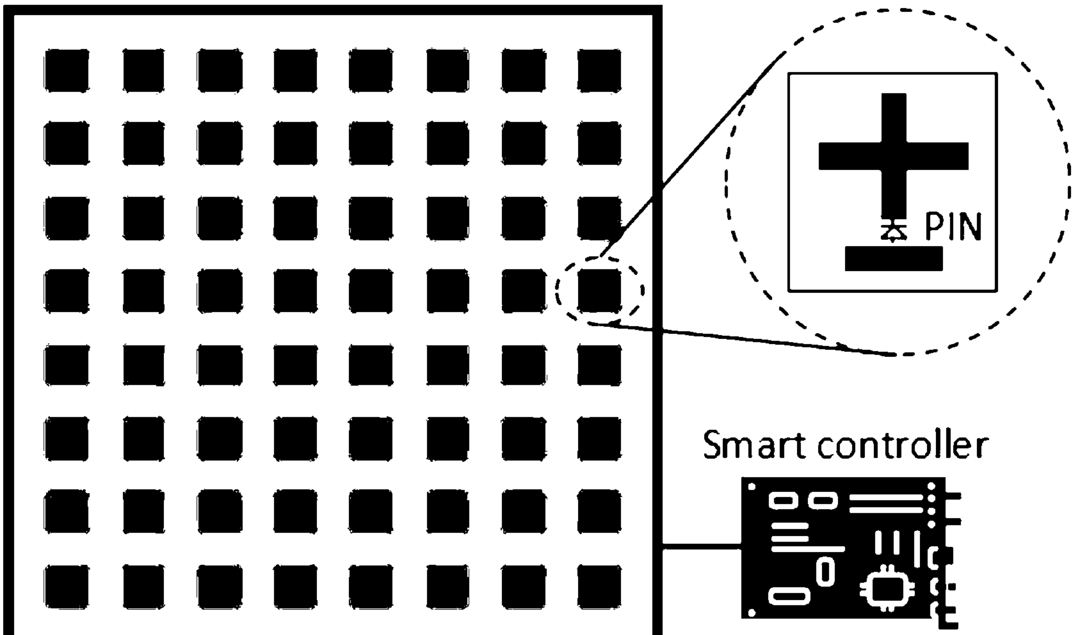

FIG. 5

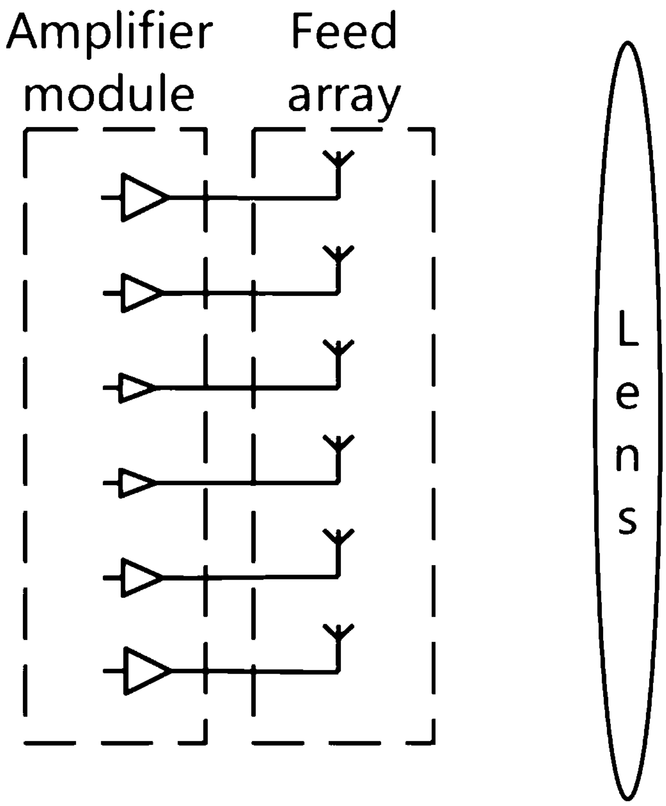

FIG. 6

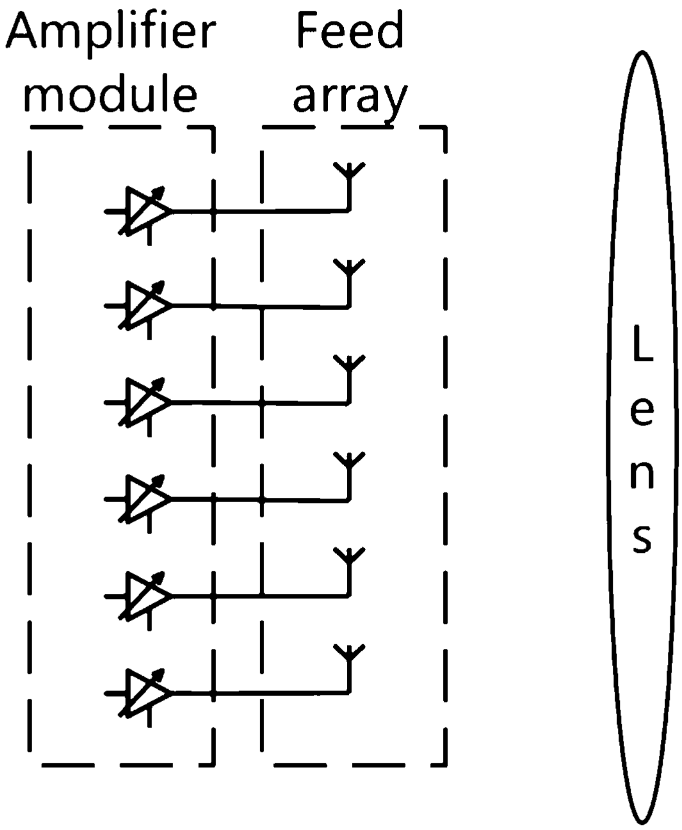

FIG. 7

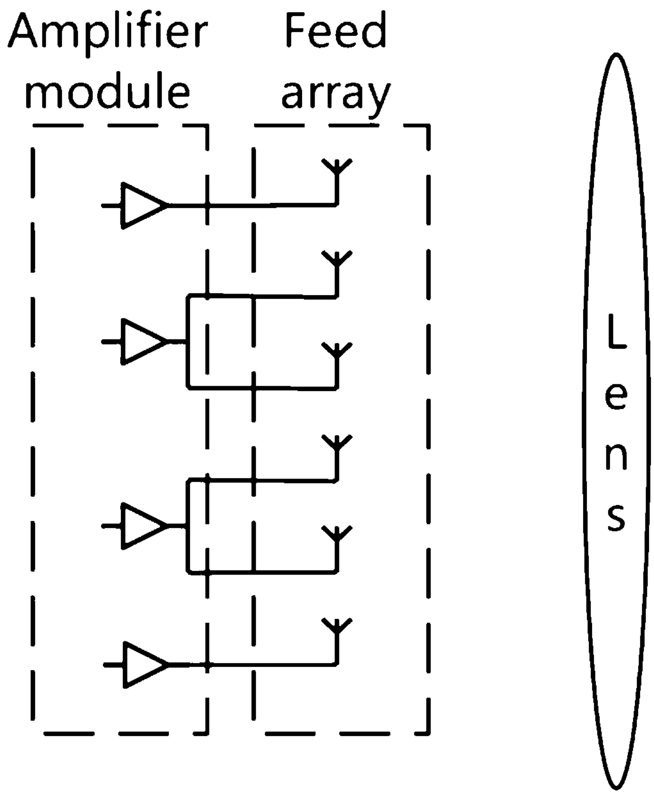

FIG. 8

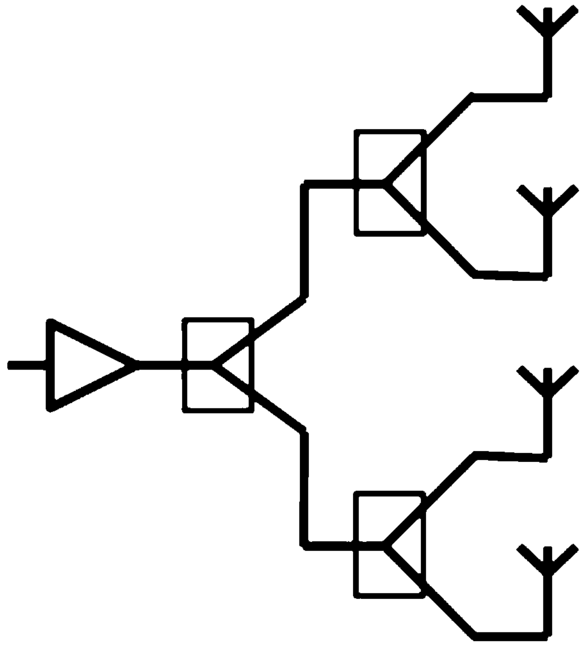

FIG. 9

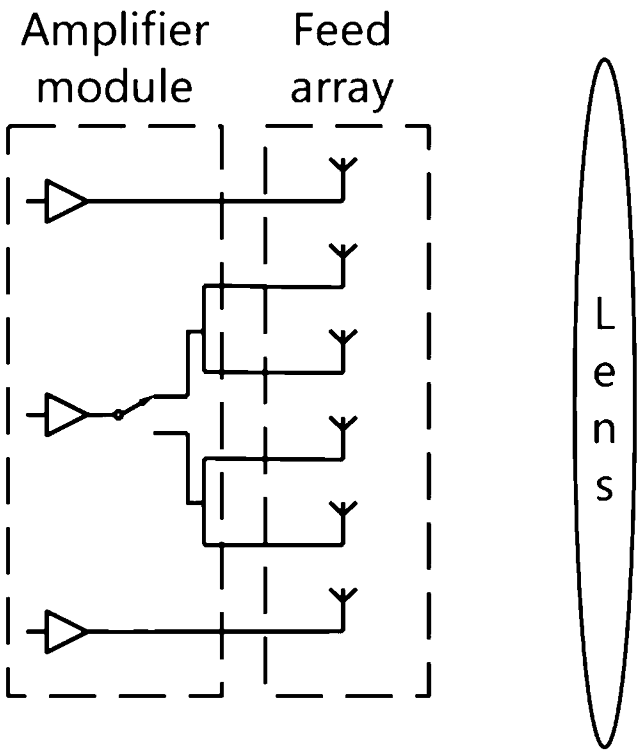

FIG. 10

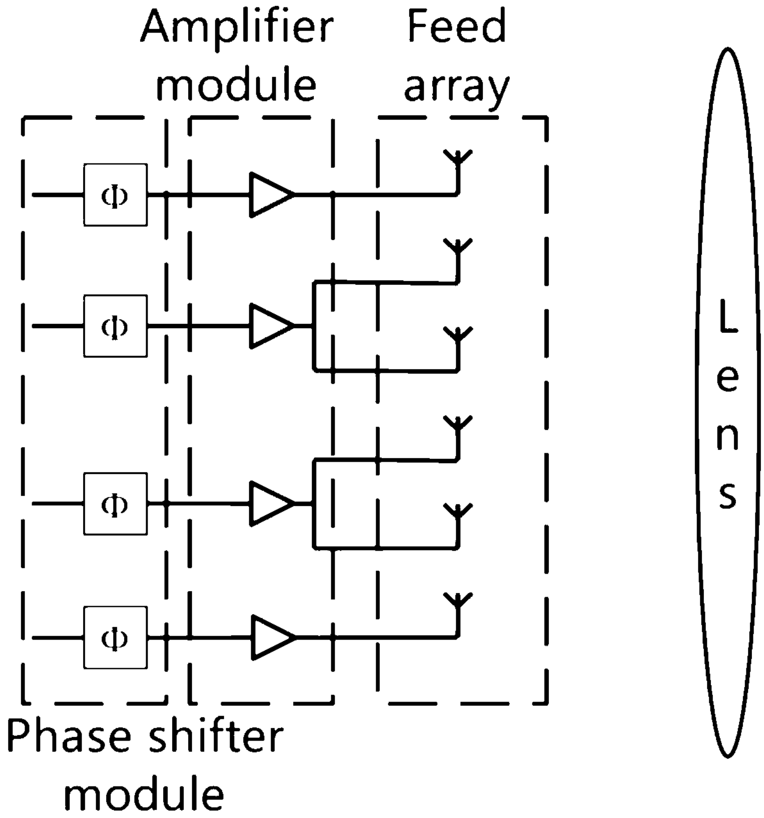
Amplifier module
Feed array
Φ
Φ
Φ
Φ
Lens
Phase shifter module

FIG. 11

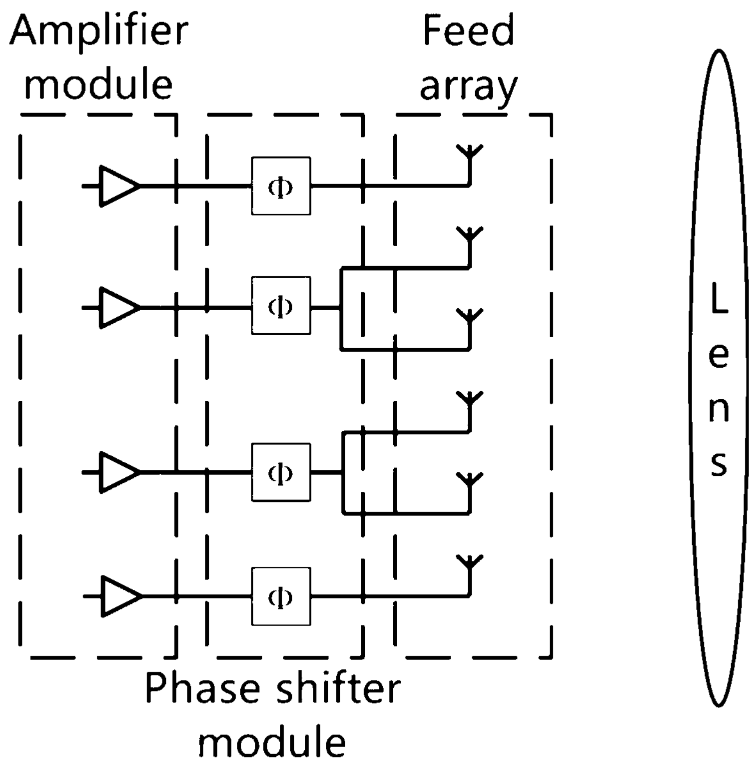
Amplifier module
Feed array
Φ
Φ
Φ
Φ
Lens
Phase shifter module

FIG. 12

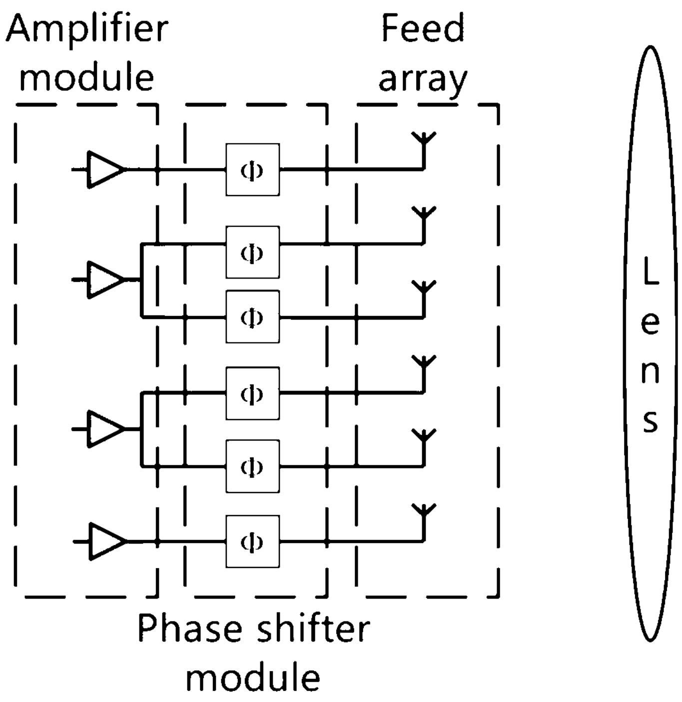
Amplifier module
Feed array
Φ
Φ
Φ
Φ
Φ
Φ
Lens
Phase shifter module

FIG. 13

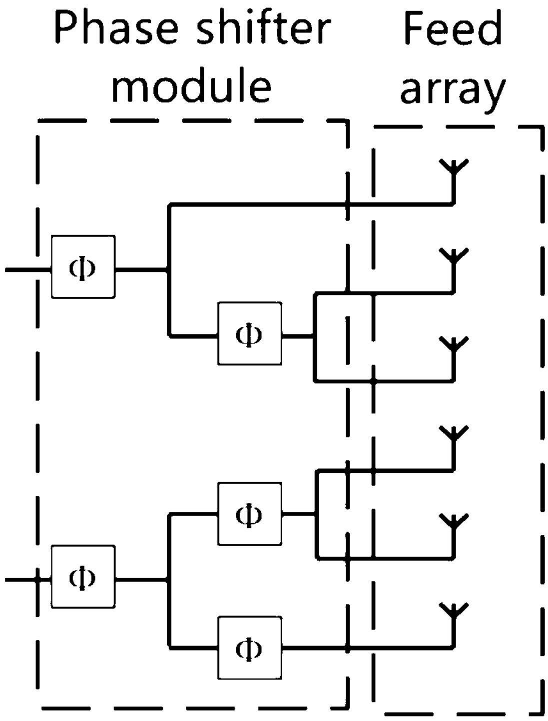

FIG. 14

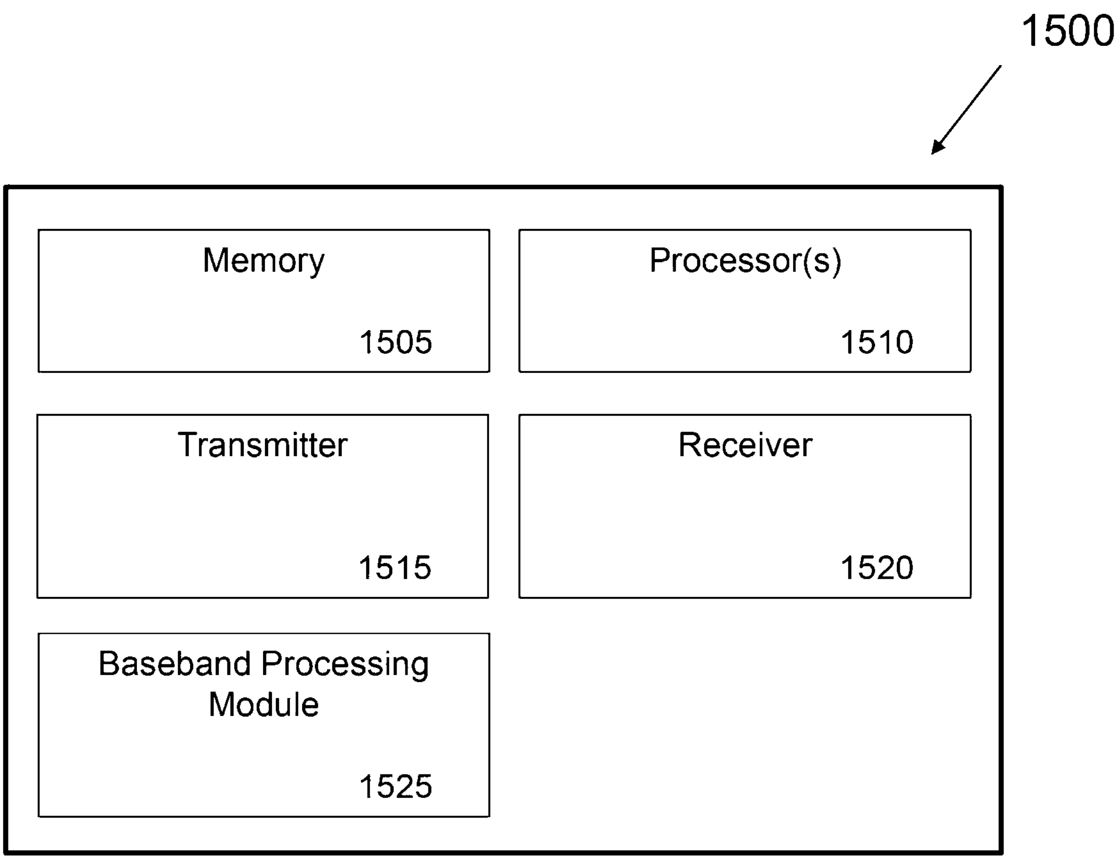
1500
Memory
1505
Processor(s)
1510
Transmitter
1515
Receiver
1520
Baseband Processing Module
1525

FIG. 15

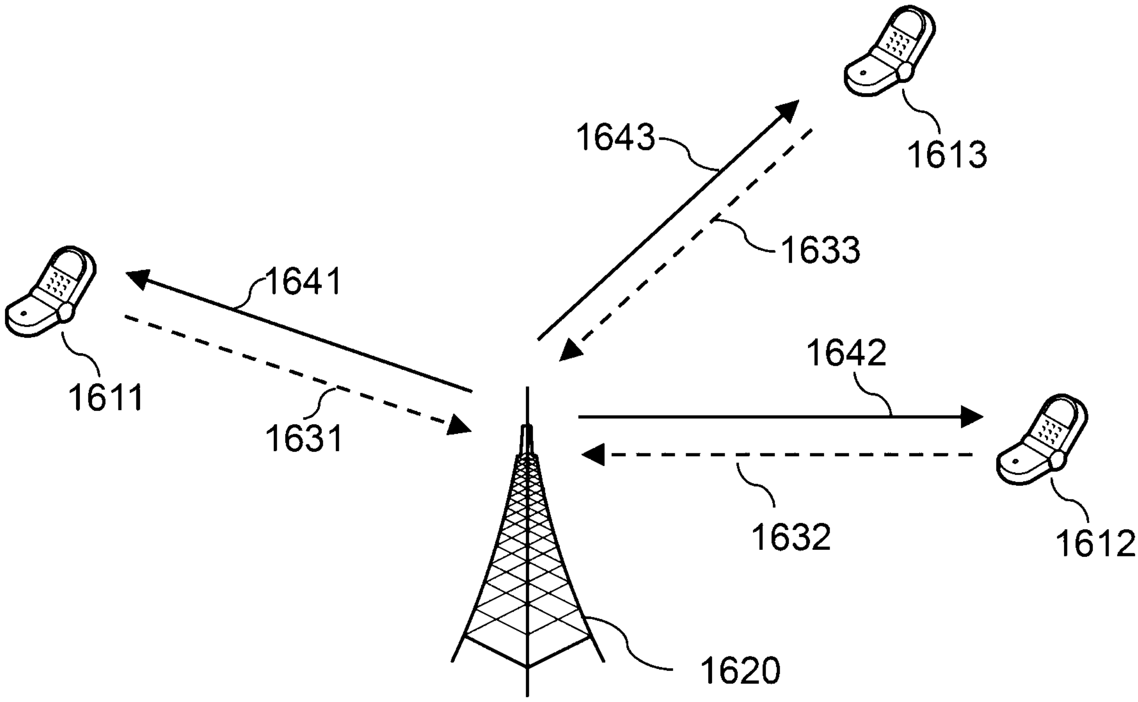

FIG. 16

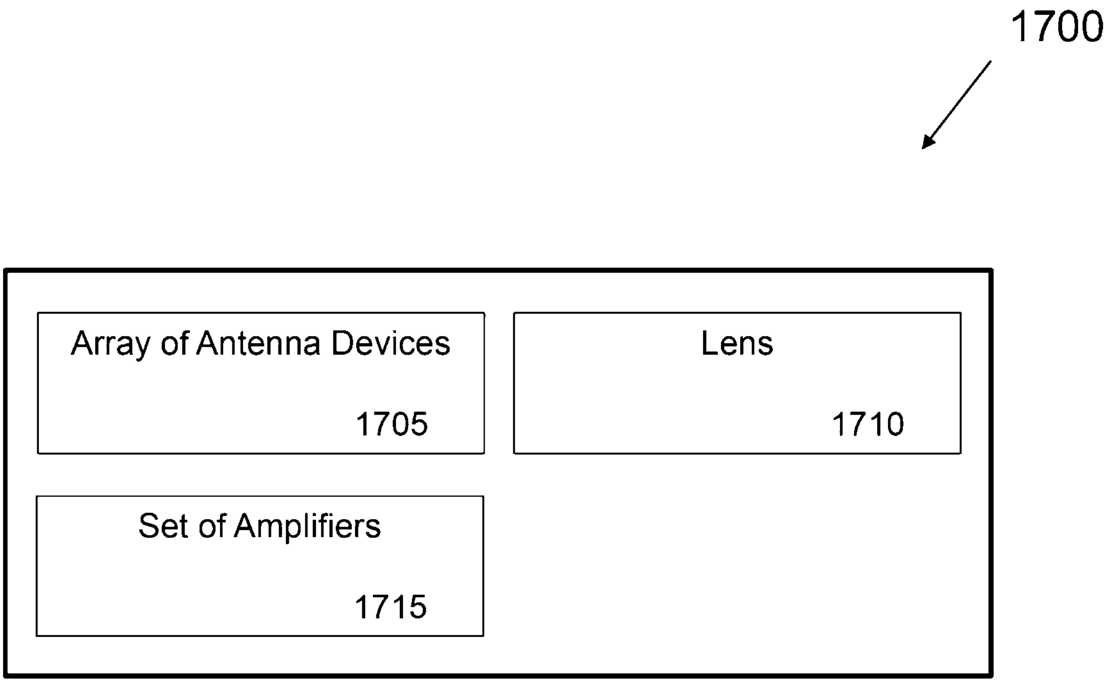
1700
Array of Antenna Devices
1705
Lens
1710
Set of Amplifiers
1715

FIG. 17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/114455

A. CLASSIFICATION OF SUBJECT MATTER

H01Q21/06(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: H01Q

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)

CNTXT;ENTXT;WPABS;VEN;CNKI;IEEE: array, lens, amplifier, gain, factor, edge, tunable

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2020212588 A1 (MOVANDI CORP) 02 July 2020 (2020-07-02) description, paragraphs [0029] to [0115] and figures 1 to 8	1-11, 13, 14
Y	US 2020212588 A1 (MOVANDI CORP) 02 July 2020 (2020-07-02) description, paragraphs [0029] to [0115] and figures 1 to 8	12, 15-17
Y	US 2010073260 A1 (DENSO CORP) 25 March 2010 (2010-03-25) description, paragraphs [0104] to [0118] and figures 1 to 11	12, 15, 16
Y	CN 115548692 A (HUAWEI TECHNOLOGIES CO., LTD.) 30 December 2022 (2022-12-30) description, paragraphs [0138] to [0166]	17
A	US 2017264014 A1 (LE-NGOC THO et al.) 14 September 2017 (2017-09-14) the whole document	1-17
A	DE 3546347 A1 (RAYTHEON CO) 10 July 1986 (1986-07-10) the whole document	1-17

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

Date of the actual completion of the international search	Date of mailing of the international search report
23 November 2023	**24 November 2023**

Name and mailing address of the ISA/CN	Authorized officer
CHINA NATIONAL INTELLECTUAL PROPERTY ADMINISTRATION **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088, China**	**LIU,Xin** Telephone No. **(+86) 010-62412157**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2023/114455

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2020212588	A1	02 July 2020	US	2021351516	A1	11 November 2021
				US	11742586	B2	29 August 2023
				US	11145986	B2	12 October 2021
US	2010073260	A1	25 March 2010		None		
CN	115548692	A	30 December 2022		None		
US	2017264014	A1	14 September 2017		None		
DE	3546347	A1	10 July 1986	US	4641144	A	03 February 1987
				GB	8531903	D0	05 February 1986
				GB	2169453	A	09 July 1986
				GB	2169453	B	01 March 1989
				FR	2575607	A1	04 July 1986
				IT	8548975	D0	20 December 1985
				IT	1181997	B	30 September 1987
				NL	8503582	A	16 July 1986