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(54) **Title:** A FLEXIBLE PRINTED CIRCUIT, AN ANTENNA MODULE, AND A WIRELESS DEVICE

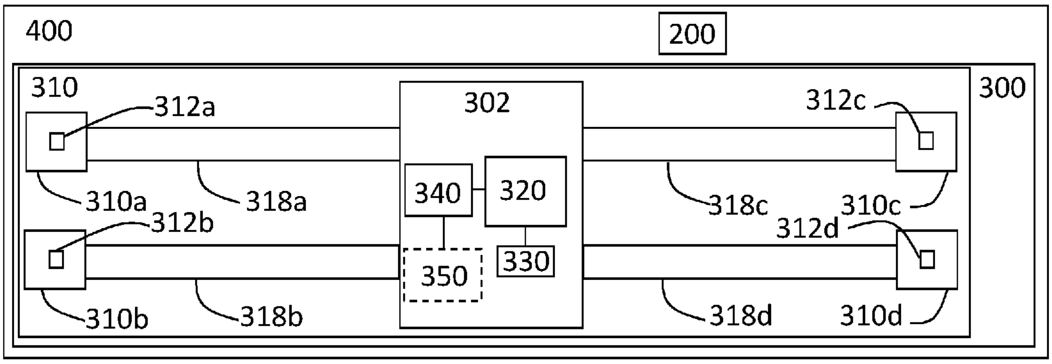

Figure 2A

(57) **Abstract:** A flexible printed circuit (100), comprising: a centre portion (102); a first end portion (110a) comprising a transceiver chip (112a), a ground plane (114a) and an antenna unit (116a); and a first elongated portion (118a), connecting the first end portion (110a) to the centre portion (102), for conveying one or more signals between the centre portion (102) and the first end portion (110a); wherein a width of the first end portion (110a) is larger than a width of the first elongated portion (118a), and wherein a length of the first end portion (110a) is larger than the width of the first elongated portion (118a). Corresponding antenna module and wireless device are also disclosed.

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A flexible printed circuit, an antenna module, and a wireless device

Technical field

The present disclosure relates to a flexible printed circuit, an antenna module, and a wireless device. More specifically, the disclosure relates to a flexible printed circuit, an antenna module, and a wireless device as defined in the introductory parts of the independent claims.

Background art

Some prior art discloses a frequency range 2 (FR2, e.g., millimetre wave) solution utilizing Antenna-in-package (AiP) technology, in which an analog beamforming architecture with antenna panels and a beamforming integrated circuit is in one module, which is connected via coaxial cables to a sub-6GHz transceiver. The output from the sub-6GHz transceiver is fed to a baseband processor.

However, such a solution may be disadvantageous, e.g., due to the clustering of antennas, because it is bulky, costly and/or needs a lot of power.

Furthermore, some prior art discloses a distributed digital beamforming solution with a transceiver chip and with the antennas integrated in one or more chips, and wherein an analog baseband signal is routed on a printed circuit board (PCB) to a digital intermediate frequency chip (or directly) to a baseband processor.

However, such a solution may be disadvantageous, e.g., since there may be issues with hardcoded PCB routing of analog signals from distributed transceiver chips (since it may require additional PCB layers). Furthermore, if the transceiver chip and/or the antenna chips are not aligned (in the same plane) with the PCB, an extra 90 degrees flipped PCB or a flexible PCB is needed, and “hard coded” to the antenna placement. Thus, the solution may be complex.

Therefore, there is a need for flexible printed circuits and/or distributed antenna modules overcoming one or more of the above-mentioned disadvantages.

Some prior art, such as US 10347967 B2 discloses antennas on a flexible PCB and some prior art, such as WO 2012/024578 A2, discloses a modular material antenna assembly that includes an antenna block having a portion with a shape that interlocks with a corresponding portion of an electrically non-conductive frame and secures the antenna block to the electrically non-conductive frame. WO 2021/115710 A1 discloses an electronic assembly comprising a flexible circuit board, which has a plurality of wiring layers, first and second circuit board sections, and a further circuit board, wherein the second circuit board section is formed with at least one flexible conductive track which electrically connects an electronic component of the first circuit board section to an electronic component of the second circuit board. Furthermore, US 2002/0180651 A1 discloses a transmission/reception apparatus, which has a first housing, a second housing, a folding section connecting the first and second housings, a first earth circuit board which has antenna circuitry thereon and is provided with the first housing, a second earth circuit board which is provided with the second housing, and a flexible conduction member for connecting the first and second earth circuit boards.

However, there is a need for improved or alternative solutions involving flexible printed circuits and/or distributed antenna modules.

Summary

An object of the present disclosure is to mitigate, alleviate or eliminate one or more of the above-identified deficiencies and disadvantages in the prior art and/or solve at least the above-mentioned problem or other problems.

According to a first aspect there is provided a flexible printed circuit, comprising: a centre portion; a first end portion comprising a transceiver chip, a ground plane and an antenna unit; and a first elongated portion, connecting the first end portion to the centre portion, for conveying one or more signals between the centre portion and the first end portion; wherein a width of the first end portion is larger than a width of the first elongated portion, and wherein a length of the first end portion is larger than the width of the first elongated portion.

According to some embodiments, the transceiver chip is centred on the first end portion, and the antenna unit is offset (or non-centred) in respect to the ground plane. Thereby tilting or direction change of the antenna gain is enabled/implemented.

According to some embodiments, the antenna gain of the antenna unit is tilted with an angle of 15-60 degrees (i.e., from 15 to 60 degrees), such as 45 degrees (of 360 degrees), relative the normal plane in a first direction by offsetting (or not centering) the ground plane, in a second direction opposite the first direction, from the antenna unit. Thereby a metallic frame (without cut through-holes) covering the edge of a wireless device comprising the flexible printed circuit may be utilized (since coverage around the edge of the wireless device is possible). Furthermore, the need for putting antennas on the frame is reduced, the manufacturing process is simplified, e.g., since there is no need to cut holes in the (metallic) frame. Moreover, the transceiver chip may be put in parallel with the flexible printed circuit.

According to some embodiments, the transceiver chip is attached to or located at/on a first side of the first end portion and the antenna unit and the ground plane are attached to or located at/on a second side, opposite to the first side, of the flexible printed circuit. Thereby the antenna unit functions as a stiffener and thus there is no need for any other/additional stiffener.

According to some embodiments, a width and a length of the ground plane is larger than a width of the first elongated portion, larger than a width of the transceiver chip, and larger than a width of the antenna unit, larger than a length of the transceiver chip, and larger than a length of the antenna unit. Thus, an improved ground plane increasing the antenna efficiency is achieved.

According to some embodiments, all signals conveyed between the centre portion and the first end portion by the first elongated portion are zero intermediate frequency (zero-IF) signals. Thereby, less interference, less noise, and/or a better signal quality is achieved. Moreover, routing is facilitated, simplified and/or reduced, e.g., due to the low bandwidth and/or frequency of the zero-IF signal. Furthermore, by utilizing a zero-IF signal the need for an intermediate down-converting step is eliminated.

According to some embodiments, the centre portion comprises one or more digital interface chips (DICs) and a digital contact interface (DICONI) for connecting the flexible printed circuit to a motherboard, and the DICONI is connected to one or more of the DICs and the transceiver chip a is connected to a respective DIC. Thereby, improved/increased replaceability/detachability/connectability is achieved.

According to some embodiments, the centre portion comprises a power management chip and optionally a real time clock for generating clock signals to the one or more DICS and/or for the transceiver chip. Thus, no clock signal needs to be routed to the flexible printed circuit or to the module. Furthermore, fewer input/output (I/O) pins are needed. Moreover, a distributed architecture with a small(er) footprint is obtained. Furthermore, the PCB design is simplified and/or has few(er) layers. Furthermore, only supply voltage needs to be routed via the interface.

According to a second aspect there is provided an antenna module comprising a flexible printed circuit, the flexible printed circuit comprising: a centre portion; first, second, third, and fourth end portions, each end portion comprising a transceiver chip, a ground plane, and an antenna unit; and a first, second, third, and fourth elongated portions, each elongated portion connecting a corresponding end portion to the centre portion, for conveying one or more signals between the centre portion and the corresponding end portion; and a width of each end portion is larger than a width of the corresponding elongated portion, and a length of each end portion is larger than the width of the corresponding elongated portion. Thus, fewer signals need to be routed on the main PCB/motherboard.

According to some embodiments, the centre portion comprises one or more digital interface chips (DICs), and a digital contact interface (DICONI), for connecting the antenna module to a motherboard, and the DICONI is connected to one or more of the DICs.

According to a third aspect there is provided a wireless device (WD) comprising: the flexible printed circuit of the first aspect (or of any of the above mentioned embodiments), the antenna module of the second aspect (or of any of the above mentioned embodiments); a motherboard comprising a baseband (BB) processor and a motherboard contact interface, corresponding to the DICONI, connected to the BB processor; and the flexible printed circuit or the antenna module is releasably connectable to the motherboard by connection of the contact interface, to the motherboard contact interface. Thereby small(er) footprint and/or simplified manufacturing of distributed antenna systems in smartphones is achieved.

Effects and features of the second, and/or third aspects are fully or to a substantial extent analogous to those described above in connection with the first aspect and vice versa.

Embodiments mentioned in relation to the first aspect are fully or largely compatible with the second, and/or third aspects and vice versa.

An advantage of some embodiments is that improved receiver performance is achieved.

Another advantage of some embodiments is that power consumption is reduced or optimized (for a wireless device).

A further advantage of some embodiments is that tilting or direction change of the antenna gain is enabled/implemented without mechanically tilting the antenna.

Yet another advantage of some embodiments is that implementation is simplified.

Yet another further advantage of some embodiments is that complexity is reduced.

Yet further advantages of some embodiments are simplified circuit design, improved (energy) efficiency, and/or reduced circuit complexity.

The present disclosure will become apparent from the detailed description given below. The detailed description and specific examples disclose preferred embodiments of the disclosure by way of illustration only. Those skilled in the art understand from guidance in the detailed description that changes, and modifications may be made within the scope of the disclosure.

Hence, it is to be understood that the herein disclosed disclosure is not limited to the particular component parts of the device described or steps of the methods described since such apparatus and method may vary. It is also to be understood that the terminology used herein is for purpose of describing particular embodiments only and is not intended to be limiting. It should be noted that, as used in the specification and the appended claims, the articles "a", "an", "the", and "said" are intended to mean that there are one or more of the elements unless the context explicitly dictates otherwise. Thus, for example, reference to "a unit" or "the unit" may include several devices, and the like. Furthermore, the words "comprising", "including", "containing" and similar wordings does not exclude other elements or steps. Moreover, the term “configured” or “adapted” is intended to mean that a unit or similar is shaped, sized, connected, connectable or otherwise adjusted for a purpose.

Brief descriptions of the drawings

The above objects, as well as additional objects, features, and advantages of the present disclosure, will be more fully appreciated by reference to the following illustrative and non-limiting detailed description of example embodiments of the present disclosure, when taken in conjunction with the accompanying drawings.

Figure 1A is a schematic top view drawing illustrating a flexible printed circuit according to some embodiments;

Figure 1B is a schematic bottom view drawing illustrating a first end portion of a flexible printed circuit according to some embodiments;

Figure 1C is a schematic top view drawing illustrating a first end portion of a flexible printed circuit according to some embodiments;

Figure 1D is a schematic drawing illustrating a centre portion of a flexible printed circuit according to some embodiments;

Figure 1E is a schematic drawing illustrating a motherboard according to some embodiments;

Figure 1F is a schematic drawing illustrating a first end portion of a flexible printed circuit according to some embodiments;

Figure 1G is a schematic drawing illustrating a centre portion of a flexible printed circuit according to some embodiments;

Figure 1H is a schematic drawing illustrating a first elongated portion of a flexible printed circuit according to some embodiments;

Figure 1I is a schematic side view drawing illustrating a first end portion of a flexible printed circuit according to some embodiments;

Figure 1J is a schematic top view drawing illustrating a first end portion of a flexible printed circuit according to some embodiments;

Figure 1K is a schematic top view drawing illustrating a first end portion of a flexible printed circuit according to some embodiments;

Figure 1L is a schematic top view drawing illustrating a first end portion of a flexible printed circuit according to some embodiments;

Figure 1M is a schematic top view drawing illustrating a first end portion of a flexible printed circuit according to some embodiments;

Figure 1N is a schematic top view drawing illustrating a first end portion of a flexible printed circuit according to some embodiments;

Figure 1O is a schematic side view drawing illustrating a first end portion of a flexible printed circuit according to some embodiments;

Figure 1P is a schematic side view drawing illustrating a first end portion of a flexible printed circuit according to some embodiments;

Figure 1Q is a schematic side view drawing illustrating a first end portion of a flexible printed circuit according to some embodiments;

Figure 2A is a schematic drawing illustrating a wireless device according to some embodiments;

Figure 2B is a schematic drawing illustrating a wireless device according to some embodiments;

Figure 3A is a schematic drawing illustrating a wireless device according to some embodiments;

Figure 3B is a schematic drawing illustrating a wireless device according to some embodiments;

Figure 4 is a schematic drawing illustrating a system comprising wireless devices and transceiver nodes according to some embodiments;

Figure 5A is a schematic rear view drawing illustrating a wireless device according to some embodiments;

Figure 5B is a schematic front view drawing illustrating a wireless device according to some embodiments;

Figure 5C is a schematic drawing illustrating a layer of a front cover of a wireless device according to some embodiments; and

Figure 5D is a schematic drawing illustrating a layer of a rear cover of a wireless device according to some embodiments.

Detailed description

The present disclosure will now be described with reference to the accompanying drawings, in which preferred example embodiments of the disclosure are shown. The disclosure may, however, be embodied in other forms and should not be construed as limited to the herein disclosed embodiments. The disclosed embodiments are provided to fully convey the scope of the disclosure to the skilled person.

Terminology

Herein is referred to a processor/processing unit. The processor may be a digital processor. Alternatively, the processor may be a microprocessor, a microcontroller, a central processing unit, a co-processor, a graphics processing unit (GPU), a digital signal processor (DSP), an image signal processor, a quantum processing unit, or an analog signal processor. The processing unit may comprise one or more processors and optionally other units, such as a control unit. Thus, the processor may be implemented as a single-processor, a dual-processor system, or a multiprocessor system. Furthermore, the invention can also be practiced in distributed computing environments where certain tasks are performed by remote processing devices that are linked through a communications network, e.g., 5G, to one or more local processors. In a distributed computing environment, program modules can be located in both local and remote memory storage devices. Moreover, some processing (e.g., for the data plane) may be moved to a centralized node, such as a centralized transceiver node (TNode). For example, baseband processing and/or higher layer processing, such as processing at layers above the physical layer, may be moved to a cloud, such as an mmW RAN cloud (wherein processing is performed by cloud processors). Such a (mmW) cloud deployment may bring significant cost savings to the operator due to centralized processing, collaborative radio processing, and availability of cheap commodity hardware.

Herein is referred to a baseband (BB) processor/processing unit. A BB processor is a processor specifically adapted for processing baseband signals/data.

Herein is referred to a control unit. A control unit may be a processor or a processing unit.

Herein is referred to millimetre Wave (mmW) utilization, mmW communication, mmW communication capability and mmW frequency range. The mmW frequency range is from

24.25 Gigahertz (GHz) to 71 GHz or more generally from 24 to 300 GHz. The mmW frequency range may also be referred to as Frequency Range 2 (FR2).

Herein is referred to a chip. A chip is an integrated circuit (chip) or a monolithic integrated circuit (chip) and may also be referred to as an IC, or a microchip.

Herein is referred to a wireless device (WD). A wireless device is any device capable of transmitting or receiving signals wirelessly. Some examples of wireless devices are user equipment (UE), mobile phones, cell phones, smart phones, Internet of Things (IoT) devices, vehicle-to-everything (V2X) devices, vehicle-to-infrastructure (V2I) devices, vehicle-to-network (V2N) devices, vehicle-to-vehicle (V2V) devices, vehicle-to-pedestrian (V2P) devices, vehicle-to-device (V2D) devices, vehicle-to-grid (V2G) devices, fixed wireless access (FWA) points, and tablets.

Herein is referred to a Transmission Configuration Indicator (TCI) State. A TCI state contains parameters for configuring a quasi-co-location relationship between one or two downlink reference signals and the Demodulation reference signal (DM-RS) ports of the physical downlink shared channel (PDSCH), the DM-RS port of physical downlink control channel (PDCCH) and/or the channel state information reference signal (CSI-RS) port(s) of a CSI-RS resource.

Herein is referred to a “transceiver node” (TNode). A TNode may be a radio unit (RRU), a repeater, a wireless node, or a base station (BS), such as a radio base station (RBS), a Node B, an Evolved Node B (eNB) or a gNodeB (gNB). Thus, a TNode may be a network (NW) node. Furthermore, a TNode may be a BS for a neighbouring cell, a BS for a handover (HO) candidate cell, a radio unit (RRU), a distributed unit (DU), another WD (e.g., a remote WD) or a base station (BS) for a (active/deactivated) secondary cell (SCell) or for a serving/primary cell (PCell, e.g., associated with an active TCI state), a laptop, a wireless station, a relay, a repeater device, a reconfigurable intelligent surface, or a large intelligent surface.

Herein is referred to an antenna unit. An antenna unit may be one single antenna. However, an antenna unit may also be a dual antenna, such as a dual patch antenna with a first (e.g., horizontal) and a second (e.g., vertical) polarization, thus functioning as two separate antennas or an antenna unit having two ports. Moreover, an antenna unit may be an antenna array, e.g., if analog beamforming is performed.

The polarization of an antenna refers to the orientation of the electric field of the radio wave transmitted by it and is determined by the physical structure of the antenna and its orientation. E.g., an antenna composed of a linear conductor (such as a dipole or whip antenna) oriented vertically will result in vertical polarization; if turned on its side the same antenna's polarization will be horizontal.

Herein is referred to a zero-intermediate frequency (zero-IF) signal or connection. An intermediate frequency (IF) is a frequency to which a carrier wave is shifted as an intermediate step in transmission or reception. The intermediate frequency is created by mixing the carrier signal with a local oscillator signal in a process called heterodyning, resulting in a signal at the difference or beat frequency. Intermediate frequencies are used in superheterodyne radio receivers, in which an incoming signal is shifted to an IF for amplification before final detection is done. A zero-IF signal is to be interpreted as a signal that does not need to go through an intermediate step in transmission or reception before being sent to a baseband processor (or to a transceiver unit), e.g., a baseband signal. Thus, a zero-IF signal can be utilized by a baseband processor (or a transceiver unit) directly.

Herein is referred to a direction. A direction refers to a direction in a multidimensional space, such as a direction in a Cartesian (or XYZ- or [x, y, z]-) coordinate system, a direction in a cylindrical coordinate system or a direction in a spherical coordinate system.

Herein is referred to an antenna gain (and the direction thereof). An antenna gain refers to the peak value of the antenna gain or to the gain in the direction of the antenna's main lobe. Furthermore, the direction of the antenna gain refers to the direction of the antenna's main lobe or to the direction of the peak value of the antenna gain.

Basic concept

A basic concept of this invention is the utilization of one or more replaceable/attachable flexible PCBs and/or the utilization of a distributed antenna module, for digital beamforming, comprising a plurality of transceiver chips (wherein each transceiver chip may be connected via a flexible/flex-film PCB to a digital interface chip). In some embodiments, the one or more flexible PCBs or the distributed antenna module has a single connection/contact towards a main PCB/motherboard, which comprises a baseband processor. By utilizing one or more flexible PCBs or a distributed antenna module, fewer signals need to be routed on the main PCB/motherboard, e.g., routing may be decreased by a factor of 10. Furthermore, in some embodiments, the antenna gain (or the direction thereof) is skewed/tilted (in relation to the antenna unit/printed circuit board), e.g., by 15-60 (i.e., from 15 to 60 degrees), such as 45, degrees. Thus, a metallic frame (without through-holes) can be placed around the edge/circumference of a wireless device without affecting/obstructing the antennas.

Embodiments

In the following, embodiments will be described where figure 1A illustrates a flexible printed circuit 100, seen from the top, according to some embodiments. The flexible printed circuit 100 may be a flexible printed circuit board (PCB) or a flexible printed circuit film. Furthermore, the flexible printed circuit 100 comprises one or more layers, such as 2 layers (e.g., a single layer and a ground layer/plane) or 3 layers (e.g., a ground layer/plane, an in-phase layer/plane, and a quadrature layer/plane). The flexible printed circuit 100 comprises a centre portion 102. Furthermore, the flexible printed circuit 100 comprises a first end portion 110a. Moreover, the flexible printed circuit 100 comprises a first elongated portion 118a. The first elongated portion 118a connects the first end portion 110a to the centre portion 102. Furthermore, the first elongated portion 118a is (utilized) for conveying one or more signals between the centre portion 102 and the first end portion 110a. Some examples of signals that can be conveyed are ground, direct current (DC) signals, local oscillator (LO) signals, intermediate frequency (IF) signals, zero intermediate frequency (zero-IF) signals, low IF signals and control signals. In some embodiments, all signals conveyed between the centre portion 102 and the first end portion 110a by the first elongated portion 118a are zero intermediate frequency (zero-IF) signals (or low IF signals). Thereby, less interference, less noise, and/or a better signal quality is achieved. Moreover, routing is facilitated, simplified and/or reduced, e.g., due to the low bandwidth and/or frequency of the zero-IF signal. Furthermore, by utilizing a zero-IF signal the need for an intermediate down-converting step is eliminated.

Figure 1B illustrates the first end portion 110a of the flexible printed circuit 100, seen from the bottom, according to some embodiments. The first end portion 110a comprises a transceiver chip 112a. The transceiver chip 112a is preferably located at and/or attached to a lower/bottom side 110L of the first end portion 110a. In some embodiments, the transceiver chip 112a is centred on the first end portion 110a. However, in some embodiments, the transceiver chip 112a is not centred (e.g., off centred) on the first end portion 110a. Furthermore, in some embodiments, the transceiver chip 112a comprises one or more of: one or more low noise amplifiers (LNAs), one or more variable gain amplifiers (VGAs), one or more phase locked loops (PLLs), one or more power amplifiers (PAs), one or more local oscillators (LOs), one or more mixers, one or more filters, and one or more other pre-processing functions/units.

Figure 1C illustrates a top view of the first end portion 110a of the flexible printed circuit 100 according to some embodiments. The first end portion 110a comprises a ground plane 114a and an antenna unit 116a. The antenna unit 116a is, in some embodiments, a patch (or microstrip) antenna. A patch antenna is an antenna with one or more elements consisting of metal sheets mounted over a ground plane (e.g., the ground plane 114a). The ground plane 114a and the antenna unit 116a are preferably located at and/or attached to an upper side 110U of the first end portion 110a. By attaching/locating the transceiver chip 112a on one side of the first end portion 110a and the antenna unit 116a on the opposite side of the first end portion 110a, the antenna unit 116a functions as a stiffener (of the flexible printed circuit) and thus there is no need for any other stiffener, which would be the case if the transceiver chip 112a was the only electrical component on the flexible printed circuit 100. Furthermore, regardless of whether the ground plane 114a is (attached) at the same side of the first end portion 110a as the antenna unit 116a (and the transceiver chip 112a is on the opposite side) or at the same side of the first end portion 110a as the transceiver chip 112a (and the antenna unit 116a is on the opposite side), the distance (in a Z-direction/height-wise) between the ground plane 114a and the antenna unit 116a is, in some embodiments, larger than the distance (in a Z-direction/height-wise) between the ground plane 114a and the transceiver chip 112a or larger than a first distance threshold value. By having a large distance (e.g., larger than the distance between the ground plane 114a and the transceiver chip 112a or larger than a first distance threshold value) between the antenna unit 116a and the ground plane 114a, the frequency band the antenna unit 116a covers is made wider (e.g., wideband). Thus, in some embodiments, the antenna unit 116a is a wideband antenna. Furthermore, if the transceiver chip 112a is made small (e.g., smaller than a size threshold value), the wires/wiring (e.g., wires for signals and/or ground) for the transceiver chip 114a need to be small as well, e.g., the wires/wiring need to be thin/narrow (thinner/narrower than a thickness threshold value). However, the impedance still needs to be suitable, such as 50-75 Ohm. By having/making the distance between the transceiver chip 112a and ground (e.g., the ground plane 114a) low/short (e.g., shorter/lower than a second distance threshold value), a suitable impedance, such as 50-75 Ohm, can be obtained while utilizing thin/narrow wires/wiring (e.g., thinner/narrower than a thickness threshold value). Thus, in some embodiments, the distance between the transceiver chip 112a and ground (e.g., the ground plane 114a) is low/short (e.g., shorter/lower than a second distance threshold value). Thus, the (successful) attachment of a transceiver chip 112a which is small (e.g., smaller than a size threshold value) is enabled/facilitated.

Figure 1D illustrates the centre portion 102 of the flexible printed circuit 100 according to some embodiments. The centre portion 102 comprises one or more digital interface chips (DICs) 120. Each DIC 120 includes/comprises one or more analog-to-digital converters (ADCs) and/or one or more digital-to-analog converters (DACs). Furthermore, the centre portion 102 comprises a digital contact interface (DICONI) 130. The DICONI 130 is (utilized) for connecting the flexible printed circuit 100 to a motherboard 200 (shown in figure 1E), e.g., for conveying/transferring signals via a serializer/deserializer (SerDes) and/or for conveying/transferring voltage signals and/or clock signals between the flexible printed circuit 100 and the motherboard 200.

Furthermore, the DICONI 130 is connected to one or more of the DICs 120. Moreover, the transceiver chip 112a is connected to a respective DIC 120. Thereby, improved/increased replaceability/detachability/connectability is achieved. In some embodiments, the centre portion 102 comprises a power management chip 140. The power management chip 140 performs or is adapted to perform power management for the one or more DICs 120 and/or for the transceiver chip 112a.

Furthermore, in some embodiments, the centre portion 102 comprises a real time clock 150 (connected to the power management chip 140). The real time clock 150 generates clock signals to the one or more DICS 120 and/or to the transceiver chip 112a. Thus, no clock signal needs to be routed to the flexible printed circuit (or to an antenna module comprising the flexible printed circuit). Furthermore, fewer I/O pins are needed. Moreover, a distributed architecture with a small(er) footprint is obtained. Furthermore, the PCB design is simplified and/or has few(er) layers. Moreover, only supply voltage needs to be routed via the DICONI.

In some embodiments, e.g., if all (electrical) components are on one side (e.g., an upper side) of the centre portion 102, the opposite side (e.g., a lower side) comprises stiffeners for stabilizing the flexible printed circuit. The stiffeners are in some embodiments stabilizing the portion of the flexible printed circuit where/to which the one or more DICS 120 are located or attached. In some embodiments, the stiffeners are made of glass-reinforced epoxy laminate material, e.g., FR4.

Figure 1E illustrates a motherboard 200 according to some embodiments. The motherboard 200 comprises a baseband (BB) processor 220. Furthermore, the motherboard 200 comprises a motherboard contact interface 230. The motherboard contact interface 230 corresponds to the DICONI 130, i.e., the motherboard contact interface 230 is releasably connectable/attachable or releasably connected/attached to the DICONI 130 (and vice versa). Furthermore, the motherboard contact interface 230 is connected to the BB processor 220. In some embodiments, the motherboard comprises other (electrical) components.

Figure 1F illustrates the first end portion 110a of the flexible printed circuit 100 according to some embodiments. The first end portion 110a has a width W1, a length L1 and a thickness (not shown). W1 and/or L1 are, in some embodiments, in the range of 3-6 mm. In some embodiments, W1 is 5 millimetres (mm) and L1 is 5 mm. Figure 1G illustrates the centre portion 102 of the flexible printed circuit according to some embodiments. The first centre portion 102 has a width W2, a length L2 and a thickness (not shown). In some embodiments, W2 and/or L2 are in the range of 5-20 mm, such as 10mm. Figure 1H illustrates the first elongated portion 118a of the flexible printed circuit 100 according to some embodiments. The first elongated portion 118a has a width W3, a length L3 and a thickness (not shown). In some embodiments, W3 is 2-3 mm and L3 is 10-60mm. The width W1 of the first end portion 110a is larger than the width W3 of the first elongated portion 118a. Furthermore, the length L1 of the first end portion 110a is larger than the width W3 of the first elongated portion 118a. By having/making the width W1 larger than the width W3 and having/making the length L1 larger than the width W3, the first elongated portion 118a does not take up unnecessary space, e.g., when comprised by a wireless device. In some embodiments, the width W1 of the first end portion 110a is substantially or significantly larger than the width W3 of the first elongated portion 118a. Furthermore, in some embodiments, the length L1 of the first end portion 110a is substantially or significantly larger than the width W3 of the first elongated portion 118a. Moreover, in some embodiments, the width W1 of the first end portion 110a is at least 2, 3, or 4 times larger than the width W3 of the first elongated portion 118a. In some embodiments, the length L1 of the first end portion 110a is at least 2, 3, or 4 times larger than the width W3 of the first elongated portion 118a. Furthermore, in some embodiments, the width W2 of the centre portion 102 is larger than the width W3 of the first elongated portion 118a. Moreover, in some embodiments, the length L2 of the centre portion 102 is larger than the width W3 of the first elongated portion 118a.

Figure 1l illustrates the first end portion 110a of the flexible printed circuit 100 shown from the side according to some embodiments. The first end portion 110a comprises one or more layers, such as a core (non-conducting) layer and/or one or more (conducting) surface layers. The first end portion 110a comprises the transceiver chip 112a. The transceiver chip 112a is preferably located at and/or attached to the lower/bottom side 110L of the first end portion 110a. The first end portion 110a comprises the ground plane 114a and the antenna unit 116a. The ground plane 114a and the antenna unit 116a are preferably located at and/or attached to the upper side 110U of the first end portion 110a. However, in some embodiments, the ground plane 114a is located at and/or attached to the lower/bottom side 110L of the first end portion 110a. The ground plane 114a is a surface layer of the first end portion 110a (or the whole first end portion 110a). In some embodiments, the antenna unit 116a is connected to the transceiver chip 112a via one or more vias 111 (running through through-holes) cutting through the ground plane 114a and one or more other (non-conducting or conducting) layers of the first end portion 110a. Furthermore, in some embodiments, both the width and the length of the ground plane 114a are larger than the width W3 of the first elongated portion 118a (i.e., the width of the ground plane 114a is larger than the width W3 of the first elongated portion 118a and the length of the ground plane 114a is larger than the width W3 of the first elongated portion 118a). Moreover, in some embodiments, both the width and the length of the ground plane 114a are larger than the width of the transceiver chip 112a (i.e., the width of the ground plane 114a is larger than the width of the transceiver chip 112a and the length of the ground plane 114a is larger than the width of the transceiver chip 112a). In some embodiments, both the width and the length of the ground plane 114a are larger than the width of the antenna unit 116a (i.e., the width of the ground plane 114a is larger than the width of the antenna unit 116a and the length of the ground plane 114a is larger than the width of the antenna unit 116a). Furthermore, in some embodiments, both the width and the length of the ground plane 114a are larger than a length of the transceiver chip

112a (i.e., the width of the ground plane 114a is larger than the length of the transceiver chip 112a and the length of the ground plane 114a is larger than the length of the transceiver chip 112a). Moreover, in some embodiments, both the width and the length of the ground plane 114a are larger than a length of the antenna unit 116a (i.e., the width of the ground plane 114a is larger than the length of the antenna unit 116a and the length of the ground plane 114a is larger than the length of the antenna unit 116a). Thus, an improved ground plane which increases the antenna efficiency is achieved.

Figures 1J-1N illustrate the first end portion 102a of the flexible printed circuit 100, seen from the top, according to some embodiments and figures 1O-1Q illustrate the first end portion 110a of the flexible printed circuit 100 shown from the side according to some embodiments. In figure 1J the first end portion 102a comprises, on the upper side 110U, the ground plane 114a and the antenna unit 116a. In some embodiments, the ground plane 114a covers the whole area (the full width and the full length of the upper side 110U) of the first end portion 102a (except for any through-holes/vias for connecting the antenna unit 116a to the transceiver unit 112a). Furthermore, in some embodiments, the antenna unit 116a covers the whole area (the full width and the full length of the upper side 110U) of the first end portion 102a. If the ground plane 114a and the antenna unit 116a both cover the whole area of the first end portion 102a, the antenna radiation/beam/gain from the antenna unit 116a is directed (substantially) straight up, i.e., in the direction from the ground plane 114a to the antenna unit 116a. In some embodiments, the antenna unit 116a is offset (e.g., spatially offset or non-centred) in respect to the ground plane 114a (or the ground plane 114a is offset in respect to the antenna unit 116a). As an example, the antenna unit 116a is spatially offset in respect to the ground plane 114a (or the ground plane 114a is spatially offset in respect to the antenna unit 116a). In some embodiments, the antenna unit 116a is spatially offset in respect to the ground plane 114a (or the ground plane 114a is spatially offset in respect to the antenna unit 116a) in one or more of a (negative or positive) X-direction and a (negative or positive) Y-direction (in an XYZ-coordinate system; the Z-direction being). Furthermore, in some embodiments, the antenna unit 116a is placed non-symmetrically in relation to a centre of the ground plane 114a (or the ground plane 114a is placed non-symmetrically in relation to a centre of the antenna unit 116a). As another example, or additionally, the antenna unit 116a is non-centred in respect to the ground plane 114a (or the ground plane 114a is non-centred in respect to the antenna unit 116a). In some embodiments, a centre of the antenna unit 116a is placed 1, 2, 3, 4, or 5 mm from the centre of the ground plane 114a (or the centre of the ground plane 114a is placed 1, 2, 3, 4, or 5 mm from the centre of the antenna unit 116a). By offsetting the antenna unit 116a in respect to the ground plane 114a, a tilting or a change of the direction of the antenna radiation/beam/gain from the antenna unit 116a is achieved. As seen in figure 1O, there is no offsetting between the ground plane 114a and the antenna unit 116a (in an XY plane). Thus, the (main) direction of the beam B from the antenna unit 116a is the same as a normal (plane), i.e., perpendicular to the upper side 110U of the first end portion 102a (i.e., the main direction of the beam B is a Z-direction or has an angle of 90 degrees upwards relative the surface of the ground plane 114a/antenna unit 116a). Furthermore, in figure 1P, the ground plane 114a covers the whole area of the first end portion 102a, whereas the antenna unit 116a only covers the left-most portion (e.g., the left-most 50%, 60%, 70%, or 80% or the 50%, 60%, 70%, or 80% with the lowest X-values) of the first end portion 102a. Thus, the beam B from the antenna unit 116a is directed away from the antenna unit 116a with an angle (other than 90 degrees, e.g., 15-60 degrees (i.e., from 15 to 60 degrees), such as 15, 45 or 60 degrees; in the negative X-direction). Moreover, in figure 1Q, the antenna unit 116a covers the whole area of the first end portion 102a, whereas the ground plane 114a only covers the right-most portion (e.g., the right-most 50%, 60%, 70%, 80% or the 50%, 60%, 70%, 80% with the highest X-values) of the first end portion 102a. Thus, the beam B from the antenna unit 116a is directed away from the antenna unit 116a with an angle (other than 90 degrees, e.g., 15-60 degrees, such as 15, 45 or 60 degrees; in the negative X-direction). Thus, the offsetting may be achieved by making/having/constructing/configuring/adapting the antenna unit 116a to be of a different size than the ground plane 114a (and not centering the antenna unit over the ground plane 114a as seen in figure 1K). Furthermore, the offsetting may be achieved by having the antenna unit 116a and the ground plane 114a of the same size but not or only partially overlapping (e.g. in a negative or positive X- and/or a Y-direction).

Moreover, as seen in figure 1J, the offsetting may be achieved by producing one or more holes or areas without metallization 115a, 115b within the ground plane 114a. In some embodiments, the one or more holes or areas without metallization 115a, 115b are placed/produced non-symmetrically around a centre of the ground plane 114a, i.e., in some embodiments, the one or more holes or areas without metallization 115a, 115b are non-centred on/in the ground plane 114a. In some embodiments, these areas without metallization 115a, 115b comprises or surrounds the one or more vias 111 (running through through-holes). Thus, manufacturing is simplified. As seen in figure 1L, the antenna unit 116a and the ground plane 114a may be partially overlapping and as seen in figure 1M, the antenna unit 116a and the ground plane 114a may be not overlapping. Another way of achieving the offsetting, as seen in figure 1N, is by introducing one or more parasitic or additional antenna elements 117a, 117b, 117c for the antenna unit 116a. In some embodiments, the one or more parasitic or additional antenna elements 117a, 117b, 117c are placed/introduced/produced non-symmetrically around a centre of the ground plane 114a, i.e., in some embodiments, the one or more parasitic or additional antenna elements 117a, 117b, 117c are non-centred on/in relation to the ground plane 114a. The additional antenna elements 117a, 117b, 117c may be one or more reflectors and/or one or more directors. Yet another way of achieving the offsetting is by combining one or more of the above-mentioned ways of achieving the offsetting. By offsetting the antenna unit 116a in respect to the ground plane 114a, tilting or a direction change of the antenna gain is enabled/implemented. Thus, the tilt/direction change may be achieved without mechanically tilting/moving the antenna.

In some embodiments, as shown in figure 1Q, the antenna gain of the antenna unit 116a is tilted or changed with an angle of 15-60 degrees (i.e., from 15 to 60 degrees), such as 45 degrees, relative the normal plane in a first direction 1D (negative X-direction) by offsetting the ground plane 114a in a second direction 2D (positive X-direction), opposite the first direction 1D (both the first and second directions 1D, 2D being in the same two-dimensional plane), from the antenna unit 116a. Thereby a metallic frame (without cut through-holes) covering/surrounding the edge of a wireless device comprising the flexible printed circuit may be utilized (since radio wave coverage around the edge of the wireless device is possible). Furthermore, the need for putting antennas on the frame is reduced, and the manufacturing process is simplified, e.g., since there is no need to cut holes in the (metallic) frame. Moreover, the transceiver chip may be put in parallel with the flexible printed circuit. Thereby, further simplifying the assembling/manufacturing.

In some embodiments, the flexible printed circuit 100 comprising the centre portion 102 comprises not just one end portion (the first end portion 110a) and one elongated portion (the first elongated portion 118a). Instead, the flexible printed circuit 100 comprises a plurality (e.g., 2, 3, 4, 6, or 16) of end portions and elongated portions, wherein each end portion is connected to the centre portion 102 by a corresponding elongated portion, and wherein each end portion and each elongated portion are (adapted) as described above (for the first end portion 110a and the first elongated portion 118a) in connection with figures 1A-1Q.

Figures 2A and 2B illustrate a wireless device (WD) 400 according to some embodiments. The WD 400 comprises a motherboard (or main PCB) 200. In some embodiments, the motherboard 200 is as described above in connection with figure 1E. Furthermore, the WD 400 comprises an antenna module 300. The antenna module 300 is replaceable/detachable and/or releasably connectable/connected to the motherboard 200. The antenna module 300 is or comprises a flexible printed circuit 310. The flexible printed circuit 310 is, in some embodiments, the same or identical to the flexible printed circuit 100 described above (e.g., comprising a plurality of end portions and elongated portions). In some embodiments, the flexible printed circuit 310 comprises a centre portion 302. The centre portion 302 is, in some embodiments, the same or identical to the centre portion 102 described above. Furthermore, the flexible printed circuit 310 comprises first, second, third, and fourth end portions 310a, 310b, 310c, 310d. Each end portion 310a, 310b, 310c, 310d comprises a transceiver chip 312a, 312b, 312c, 312d, a ground plane 314a, 314b, 314c, 314d and an antenna unit 316a, 316b, 316c, 316d. In some embodiments, each end portion 310a, 310b, 310c, 310d (and each transceiver chip 312a, 312b, 312c, 312d, ground plane 314a, 314b, 314c, 314d and antenna unit 316a, 316b, 316c, 316d) is the same or identical to the end portion 110a (the transceiver chip 112a, the ground plane 114a and the antenna unit 116a) described above in connection with figures 1A-1Q. Moreover, the flexible printed circuit 310 comprises first, second, third, and fourth elongated portions 318a, 318b, 318c, 318d. Each elongated portion 318a, 318b, 318c, 318d connects a corresponding end portion 310a, 310b, 310c, 310d to the centre portion 302. Each elongated portion 318a, 318b, 318c, 318d is for conveying or conveys one or more signals between the centre portion 302 and the corresponding end portion 310a, 310b, 310c, 310d. In some embodiments, each elongated portion 318a, 318b, 318c, 318d is the same or identical to the elongated portion 118a described above in connection with figures 1A-1Q. A/the width of each end portion 310a, 310b, 310c, 310d is larger than a/the width of the corresponding elongated portion 318a, 318b, 318c, 318d. Furthermore, a length of each end portion 310a, 310b, 310c, 310d is larger than the width of the corresponding elongated portion 318a, 318b, 318c, 318d. Thus, fewer signals need to be routed on the main PCB/motherboard 200. As an example, the number of signals/lines that needs to be routed may be decreased from 150-300 to 8-16, i.e., decreased by a factor of 10-20.

In some embodiments, the centre portion 302 comprises one or more digital interface chips, DICs, 320 and a digital contact interface (DICONI) 330. The DICONI 330 is (utilized) for connecting the antenna module 300 to the motherboard 200. Furthermore, in some embodiments, the DICONI 330 is connected to one or more of the DICs 320. In some embodiments, the centre portion 302 comprises a power management chip 340. Furthermore, in some embodiments, the centre portion 302 comprises a real time clock 350 (connected to the power management chip 340). Moreover, in some embodiments, the centre portion 302 comprises a number of DICs 320, and the number of DICs is lower than the number of transceiver chips 312a, 312b, 312c, 312d (comprised by the end portions 310a, 310b, 310c, 310d). As an example, the number of DICs 320 is 1 or 2, the number of transceiver chips 312a, 312b, 312c, 312d per DIC 320 is 4, 5, 6, 7, 8, 10 or 12, and each transceiver chip 312a, 312b, 312c, 312d is associated with and/or connected to a corresponding DIC 320. As another example, the number of DICs 320 is 3 or 4, the number of transceiver chips 312a, 312b, 312c, 312d per DIC 320 is 4, 5, 6, 7, 8, 10 or 12, and each transceiver chip 312a, 312b, 312c, 312d is associated with and/or connected to a corresponding DIC 320. As yet another example, the number of DICs 320 is 5, 6, 7 or 8, the number of transceiver chips 312a, 312b, 312c, 312d per DIC 320 is 4, 5, 6, 7, 8, 10 or 12, and each transceiver chip 312a, 312b, 312c, 312d is associated with and/or connected to a corresponding DIC 320. Alternatively, the centre portion 302 comprises the same number of DICs 320 as the number of transceiver chips 312a, 312b, 312c, 312d (comprised by the end portions 310a, 310b, 310c, 310d), e.g., 4, and each DIC 320 is associated with and/or connected to a corresponding transceiver chip 312a, 312b, 312c, 312d.

Figures 3A and 3B illustrate a wireless device (WD) 400 according to some embodiments. The WD 400 comprises a motherboard (or main PCB) 200. In some embodiments, the motherboard 200 is as described above in connection with figure 1E. Furthermore, the WD 400 comprises an antenna module 300a. The antenna module 300a is replaceable/detachable and/or releasably connectable/connected to the motherboard 200. Furthermore, the antenna module 300a is or comprises a flexible printed circuit 310x. The flexible printed circuit 310x is, in some embodiments, the same or identical to one or more of the flexible printed circuit 100 and the flexible printed circuit 300 described above. In some embodiments, the flexible printed circuit 310a comprises a centre portion 302a. The centre portion 302a is, in some embodiments, the same or identical to the centre portion 102 or the centre portion 302 described above. Furthermore, the flexible printed circuit 310a comprises first, second, third, fourth, fifth, sixth, seventh, and eighth end portions 310a, 310b, 310c, 310d, 310e, 310f, 310g, 310h. Each end portion 310a, 310b, 310c, 310d, 310e, 310f, 310g, 310h comprises a transceiver chip 312a, 312b, 312c, 312d, 312e, 312f, 312g, 312h, a ground plane 314a, 314b, 314c, 314d, 314e, 314f, 314g, 314h and an antenna unit 316a, 316b, 316c, 316d, 316e, 316f, 316g, 316h. In some embodiments, each end portion 310a, 310b, 310c, 310d, 310e, 310f, 310g, 310h (and each transceiver chip 312a, 312b, 312c, 312d, 312e, 312f, 312g, 312h, ground plane 314a, 314b, 314c, 314d, 314e, 314f, 314g, 314h and antenna unit 316a, 316b, 316c, 316d, 316e, 316f, 316g, 316h) is the same or identical to the end portion 110a (the transceiver chip 112a, the ground plane 114a and the antenna unit 116a) described above in connection with figures 1A-1Q. Moreover, the flexible printed circuit 310a comprises a first, second, third, fourth, fifth, sixth, seventh, and eighth elongated portions 318a, 318b, 318c, 318d, 318e, 318f, 318g, 318h. Each elongated portion 318a, 318b, 318c, 318d, 318e, 318f, 318g, 318h connects a corresponding end portion 310a, 310b, 310c, 310d, 310e, 310f, 310g, 310h to the centre portion 302a. Each elongated portion 318a, 318b, 318c, 318d, 318e, 318f, 318g, 318h is for conveying or conveys one or more signals between the centre portion 302a and the corresponding end portion 310a, 310b, 310c, 310d, 310e, 310f, 310g, 310h. In some embodiments, each elongated portion 318a, 318b, 318c, 318d, 318e, 318f, 318g, 318h is the same or identical to the elongated portion 118a described above in connection with figures 1A-1Q. A/the width of each end portion 310a, 310b, 310c, 310d, 310e, 310f, 310g, 310h is larger than a/the width of the corresponding elongated portion 318a, 318b, 318c, 318d, 318e, 318f, 318g, 318h. Furthermore, a length of each end portion 310a, 310b, 310c, 310d, 310e, 310f, 310g, 310h is larger than the width of the corresponding elongated portion 318a, 318b, 318c, 318d, 318e, 318f, 318g, 318h. Thus, fewer signals need to be routed on the main PCB/motherboard 200.

In some embodiments, the centre portion 302a comprises one or more digital interface chips, DICs, 320a and a digital contact interface (DICONI) 330a. The DICONI 330a is (utilized) for connecting the antenna module 300a to a motherboard 200. Furthermore, in some embodiments, the DICONI 330a is connected to one or more of the DICs 320a. In some embodiments, the centre portion 302a comprises a power management chip 340a. Furthermore, in some embodiments, the centre portion 302a comprises a real time clock 350 (connected to the power management chip 340a). Moreover, in some embodiments, the centre portion 302a comprises the same number of DICs 320a as the number of transceiver chips 312a, 312b, 312c, 312d, 312e, 312f, 312g, 312h, e.g., 8, and each DIC 320a is associated with and/or connected to a corresponding transceiver chip 312a, 312b, 312c, 312d, 312e, 312f, 312g, 312h.

In some embodiments, the wireless device (WD) 400 comprises the flexible printed circuit 100, 300, 300a described above and/or the antenna module 300, 300a described above. Furthermore, the WD 400 comprises a motherboard (or main PCB) 200. The motherboard comprises a baseband (BB) processor 220. Furthermore, the motherboard 200 comprises a motherboard contact interface 230. The motherboard contact interface 230 corresponds to the DICONI 130, 330, 330a and is releasably connectable or releasably connected to the DICONI 130, 330, 330a, i.e., the motherboard contact interface 230 fits together with the DICONI 130, 330, 330a. Furthermore, the motherboard contact interface 230 is connected to the BB processor 220. Moreover, the flexible printed circuit 100 or the antenna module 300, 300a is releasably connectable/attachable to the motherboard 200. Alternatively, the flexible printed circuit 100 or the antenna module 300, 300a is releasably connected/attached to the motherboard 200 (e.g., after the contact interface 130, 330 has been connected to the motherboard contact interface 230). The releasable connection of the flexible printed circuit 100 or the antenna module 300, 300a to the motherboard 200 is performed/implemented by connecting the contact interface 130, 330, 330a to the motherboard contact interface 230. Thereby a small(er) footprint and/or a simplified manufacturing of distributed antenna systems in WDs/smart phones is achieved (compared to prior art). The WD 400 comprises an outer rim/border 409 (shown in figure 4). In some embodiments, the WD 400 comprises a metallic frame (a frame made of metal). Furthermore, in some embodiments, the metallic frame covers/surrounds (e.g., all of or a substantial part of) the outer rim/border 409 (e.g., the entire outer rim/border 409). Moreover, in some embodiments, the metallic frame is without through-holes. Thus, manufacturing is simplified and/or faster.

By utilizing a flexible printed circuit 100 or an antenna module 300, 300a comprising a flexible printed circuit 310, 310a in/inside a WD 400, the flexible printed circuit 100, 300, 300a may be bent or folded (e.g., wrapped around the motherboard 200), and thus the antenna unit(s) 116a, 316a, 316b, 316c, 316d, 316e, 316f, 316g, 316h may be directed in suitable/different directions (just by bending/folding the flexible printed circuit 100, 300, 300a). Thus, distribution of the antenna unit(s) 116a, 316a, 316b, 316c, 316d, 316e, 316f, 316g, 316h in three-dimensional space is simplified. Furthermore, no calibration is needed.

Moreover, in some embodiments, the transceiver chip(s) 112a, 312a, 312b, 312c, 312d, 312e, 312f, 312g, 312h, the end portion(s) 310a, 310b, 310c, 310d, 310e, 310f, 310g, 310h, and/or the elongated portion(s) 318a, 318b, 318c, 318d, 318e, 318f, 318g, 318h are fastened with/using double-sided tape (or a resin/gum) on the frame, on/at the backside, and/or on/at the front side of the WD 400. Thus, the fastening procedure is simple/simplified. Furthermore, replacement of components, such as a display, is easy/easier/simplified.

Figure 4 illustrates a system 999. The system 999 may be a wireless/cellular communication system, a cellular network, a mobile network, a telecommunications network, a cellular radio system, a digital cellular network, a mobile phone network, a mobile phone cellular network, such as 1G, 2G, 3G, 4G, 5G, 6G or similar. Furthermore, the system 999 comprises one or more wireless devices (WD) 400, 401, ..., 408. Moreover, the system 999 comprises one or more transceiver nodes (TNodes) 397, 398, 399. The one or more transceiver nodes (TNodes) 397, 398, 399 may be base stations (gNBs, eNBs, RBS), remote radio units (RRUs), or remote wireless nodes. The WD 400 (as well as the WDs 401, ..., 408) is, in some embodiments, configured to communicate with (e.g., send and/or receive signals, such as radio signals, e.g., comprising baseband/information signals, to/from) one or more of the remote transceiver nodes (TNodes) 397, 398, 399. In some embodiments, the WD 400 (as well as the WDs 401, ..., 408) comprises a metallic frame (i.e., a frame made of metal). Furthermore, in some embodiments, the metallic frame covers/surrounds (e.g., all of or a substantial part of) the outer rim/border 409, e.g., the entire outer rim/border 409.

Figure 5A illustrates the rear/back of the wireless device (WD) 400 according to some embodiments. The WD 400 comprises a rear/back cover 402. In some embodiments, the rear cover 402 has a thickness of between 0.3 mm and 1.5 mm. Furthermore, the rear cover 402 is made of glass, glass-ceramic, plastic, plastic-ceramic, ceramic, sapphire, or other substantially transparent material, component, or assembly. The rear cover 402 is formed as a single piece or unitary sheet. Alternatively, the rear cover 402 is formed as a composite of multiple layers of different materials, coatings, and other elements. In some embodiments, the WD 400 comprises a camera 410 and one or more buttons (not shown). The camera 410 and the one or more buttons are located at the rear/back of the WD 400. Figure 5B illustrates the front of the wireless device (WD) 400 according to some embodiments. The WD 400 comprises a front cover 404. In some embodiments, the front cover 404 has a thickness of between 0.3 mm and 1.5 mm. Furthermore, the front cover 404 is made of glass, glass-ceramic, plastic, plastic-ceramic, ceramic, sapphire, or other substantially transparent material, component, or assembly. The front cover 404 is formed as a single piece or unitary sheet. Alternatively, the front cover 404 is formed as a composite of multiple layers of different materials, coatings, and other elements. In some embodiments, the WD 400 comprises a display 420. The display 420 is located (e.g., immediately) behind/underneath the front cover 404, i.e., the front cover 404 may be positioned over the display 420.

Figure 5C illustrates an antenna layer 430 of the front cover 404 according to some embodiments. As mentioned above, the front cover 404 may be formed of multiple layers. The multiple layers may be/comprise a top/outermost layer (not shown) and a first antenna layer 430 (e.g., located immediately behind/underneath the top layer). In some embodiments, the antenna layer 430 comprises one or more antenna units, such as one or more patch antennas, 316a, 316b, 316c, 316d. Preferably, the one or more antenna units, 316a, 316b, 316c, 316d are located outside the area of the display 420. However, one or more of the antenna units 316a, 316b, 316c, 316d may be located on top of the display 420. Figure 5D illustrates an antenna layer 440 of the rear cover 402 according to some embodiments. As mentioned above, the rear cover 402 may be formed of multiple layers. The multiple layers may be a top/outermost layer (not shown) and a second antenna layer 440 (e.g., located immediately behind/underneath the top layer). In some embodiments, the second antenna layer 440 comprises one or more antenna units, such as one or more patch antennas, 316e, 316f, 316g, 316h.

In some embodiments, one or more antenna units 116a, 316a, 316b, 316c, 316d, 316e, 316f, 316g, 316h (and/or additional antenna elements 117a, 117b, 117c) are located at a rear cover 402 or at front cover 404 of a WD 400. As an example, one or more antenna units 116a, 316a, 316b, 316c, 316d, 316e, 316f, 316g, 316h (and/or additional antenna elements 117a, 117b, 117c) are embedded in the rear/front cover 402, 404 or located at (and attached to) an inner surface (back side) of the rear/front cover 402, 404 or a top/outermost layer thereof. Alternatively, the rear/front cover 402, 404 comprises multiple layers, and an antenna layer 430, 440 (e.g., other than the top/outermost layer) comprises one or more antenna units

116a, 316a, 316b, 316c, 316d, 316e, 316f, 316g, 316h (and/or additional antenna elements 117a, 117b, 117c). As another alternative, the one or more antenna units 116a, 316a, 316b, 316c, 316d, 316e, 316f, 316g, 316h (and/or additional antenna elements 117a, 117b, 117c) are located at an edge/rim/border of the rear/front cover 402, 404, e.g., between the rear/front cover 402, 404 and a metallic frame covering/surrounding the outer rim/border 409 of the WD 400. By moving one or more antenna units 116a, 316a, 316b, 316c, 316d, 316e, 316f, 316g, 316h (and/or additional antenna elements 117a, 117b, 117c) from the interior of the WD 400 to the rear cover 402 and/or the front cover 404 of the WD 400, space (e.g., in the interior of the WD 400) is saved, and the WD 400 can thus be made thinner. Furthermore, if the rear cover 402 and/or the front cover 404 is (at least partially) made of e.g., glass (or another material with a dielectric constant higher than a dielectric threshold value), the thermal management is improved (e.g., the heat dissipation or the relative permittivity is increased) by putting one or more antenna units in/at the front/rear cover of the WD (compared to arranging the antenna units in the interior of the WD 400). Thus, reliability of the WD is improved.

In some embodiments, the antenna unit 116a is a flat antenna unit (i.e., the length is larger than the height and the width is larger than the height; or the antenna unit 116a extends further in the X- and Y-directions than in the Z-direction; is in a horizontal position). Furthermore, in some embodiments, the ground plane 114a is flat (i.e., the length is larger than the height and the width is larger than the height; or the ground plane 114a extends further in the X- and Y-directions than in the Z-direction; or is in a horizontal position), and the antenna unit 116a is in parallel to the ground plane 114a when/while located at and/or attached to an upper side 110U of the first end portion 110a. Moreover, in some embodiments, the transceiver chip 112a is flat (i.e., the length is larger than the height and the width is larger than the height; or the transceiver chip 112a extends further in the X- and Y-directions than in the Z-direction; is in a horizontal position), and the transceiver chip 112a is in parallel to the ground plane 114a when/while located at and/or attached to a lower/bottom side 110L of the first end portion 110a.

In some embodiments, the offsetting of the antenna unit 116a in respect to the ground plane 114a (or the offsetting of the ground plane 114a in respect to the antenna unit 116a) comprises offsetting an angle of the antenna gain of the antenna unit 116a relative a normal vector of a surface of the first end portion 110a onto which the antenna unit 116a is attached.

Generally, all terms used herein are to be interpreted according to their ordinary meaning in the relevant technical field, unless a different meaning is clearly given and/or is implied from the context in which it is used. Reference has been made herein to various embodiments. However, a person skilled in the art would recognize numerous variations to the described embodiments that would still fall within the scope of the claims. For example, the method embodiments described herein discloses example methods through steps being performed in a certain order. However, it is recognized that these sequences of events may take place in another order without departing from the scope of the claims. Furthermore, some actions/method steps may be performed in parallel even though they have been described as being performed in sequence. Thus, the steps of any methods disclosed herein do not have to be performed in the exact order disclosed, unless a step is explicitly described as following or preceding another step and/or where it is implicit that a step must follow or precede another step. In the same manner, it should be noted that in the description of embodiments, the partition of functional blocks into particular units is by no means intended as limiting. Contrarily, these partitions are merely examples. Functional blocks described herein as one unit may be split into two or more units. Furthermore, functional blocks described herein as being implemented as two or more units may be merged into fewer e.g., a single) unit. Any feature of any of the embodiments/aspects disclosed herein may be applied to any other embodiment/aspect, wherever suitable. Likewise, any advantage of any of the embodiments may apply to any other embodiments, and vice versa. Hence, it should be understood that the details of the described embodiments are merely examples brought forward for illustrative purposes, and that all variations that fall within the scope of the claims are intended to be embraced therein.

List of some acronyms and abbreviations that may appear in the description

3GPP - 3rd Generation Partnership Project

5G - fifth generation

5G - NR (5G - New Radio) is a new RAT developed by 3GPP for the 5G mobile network

ADC - analog-to-digital converter

AGC - automatic gain controller

AiP - Antenna-in-package

BB - baseband

BF – beamforming

BW – bandwidth

BWP – bandwidth part

CSI-RS - channel state information reference signal

CU - control unit

DAC - digital-to-analog converter

DC - direct current

DCI - downlink control information

DIC – Digital Interface Chip

DICONI - digital contact interface

DL-PRS - downlink positioning reference signal

DM-RS - demodulation reference signal

DS - down-sampling

FR1 - Frequency Range 1

FR1.5 - Frequency Range 1.5

FR2 - Frequency Range 2

Fe - Front end

FWA - Fixed Wireless Access

GNSS - Global navigation satellite system

GPS – Global Positioning System

IF - intermediate frequency

I/O – input/output

L1 – Layer 1

LNA - Low Noise Amplifier

LO - Local Oscillator

LoS – Line of Sight

LTE - Long-Term Evolution

MAC - Medium Access Control

MATARA – multi-antenna transmitter and receiver arrangement

MIMO – multiple input, multiple output

mmW - millimetre wave

NAS - Non-access Stratum

nLoS – non-Line of Sight

OFDM - orthogonal frequency-division multiplexing

PA - power amplifier

PBCH - Physical Broadcast Channel

PCB - printed circuit board

PCell - primary cell

PDCCH - physical downlink control channel

PDP - Power delay profile

PDSCH - physical downlink shared channel

PHY - Physical Layer

PLL - phase locked loop

PSCell - primary secondary cell

PSS - primary synchronization signal

PT-RS - Phase Tracking Reference signal

PUCCH - physical uplink control channel

PUSCH - physical uplink shared channel

QCL - quasi co-located

QoS – quality of service

RAT - radio access technology

RRC - radio resource control

RSRP - Reference Signal Received Power

RSRQ - Reference Signal Received Quality

RSSI - Received Signal Strength Indicator

SCell - Secondary Cell

SerDes - serializer/deserializer

SNR - Signal-to-noise ratio

SSB - Synchronization Signal Block

SRS - sounding reference signal

SSS - secondary synchronization signal

STEF - spatio-temporal filter

STF – spatial transmission filter

TCI - Transmission Configuration Indicator

TNode – transceiver node

VGA - variable gain amplifier

WD - wireless device

CLAIMS

1. A flexible printed circuit (100), comprising:

a centre portion (102);

a first end portion (110a) comprising a transceiver chip (112a), a ground plane (114a) and an antenna unit (116a); and

a first elongated portion (118a), connecting the first end portion (110a) to the centre portion (102), for conveying one or more signals between the centre portion (102) and the first end portion (110a);

wherein a width of the first end portion (110a) is larger than a width of the first elongated portion (118a), and wherein a length of the first end portion (110a) is larger than the width of the first elongated portion (118a).

2. The flexible printed circuit of claim 1, wherein the transceiver chip (112a) is centred on the first end portion (110a) and wherein the antenna unit (116a) is offset in respect to the ground plane (114a).

3. The flexible printed circuit of claim 2, wherein the antenna gain of the antenna unit (116a) is tilted with an angle of 15-60 degrees, such as 45 degrees, relative the normal plane in a first direction by offsetting the ground plane (114a), in a second direction opposite the first direction, from the antenna unit (116a).

4. The flexible printed circuit of any of claims 1-3, wherein the transceiver chip (112a) is attached to or located at/on a first side (110U) of the first end portion (110a) and wherein the antenna unit and the ground plane are attached to or located at/on a second side (110L), opposite to the first side (110U), of the flexible printed circuit (100).

5. The flexible printed circuit of any of claims 1-4, wherein a width and a length of the ground plane (114a) is larger than a width of the first elongated portion (118a), larger than a width of the transceiver chip (112a), larger than a width of the antenna unit (116a), larger than a length of the transceiver chip (112a), and larger than a length of the antenna unit (116a).

6. The flexible printed circuit of any of claims 1-5, wherein all signals conveyed between the centre portion (102) and the first end portion (110a) by the first elongated portion (118a) are zero intermediate frequency, zero-IF, signals.

7. The flexible printed circuit of any of claims 1-6, wherein the centre portion (102) comprises one or more digital interface chips, DICs, (120) and a digital contact interface, DICONI, (130) for connecting the flexible printed circuit (100) to a motherboard (200), and wherein the DICONI (130) is connected to one or more of the DICs (120) and wherein the transceiver chip (112a) is connected to a respective DIC (120).

8. The flexible printed circuit of claim 7, wherein the centre portion (102) comprises a power management chip (140) and optionally a real time clock for generating clock signals to the one or more DICS (120) and/or for the transceiver chip (112a).

9. An antenna module (300) comprising a flexible printed circuit (310), the flexible printed circuit (310) comprising:

a centre portion (302);

first, second, third, and fourth end portions (310a, 310b, 310c, 310d), each end portion (310a, 310b, 310c, 310d) comprising a transceiver chip (312a, 312b, 312c, 312d), a ground plane (314a, 314b, 314c, 314d) and an antenna unit (316a, 316b, 316c, 316d); and

a first, second, third, and fourth elongated portions (318a, 318b, 318c, 318d), each elongated portion (318a, 318b, 318c, 318d) connecting a corresponding end portion (310a, 310b, 310c, 310d) to the centre portion (302), for conveying one or more signals between the centre portion (302) and the corresponding end portion (310a, 310b, 310c, 310d);

wherein a width of each end portion (310a, 310b, 310c, 310d) is larger than a width of the corresponding elongated portion (318a, 318b, 318c, 318d), and wherein a length of each end portion (310a, 310b, 310c, 310d) is larger than the width of the corresponding elongated portion (318a, 318b, 318c, 318d).

10. The antenna module of claim 9, wherein the centre portion (302) comprises one or more digital interface chips, DICs, (320) and a digital contact interface, DICONI, (330) for connecting the antenna module (300) to a motherboard (200), and wherein the DICONI (330) is connected to one or more of the DICs (320).

11. A wireless device, WD, (400), comprising:

the flexible printed circuit (100) of any of claims 7-8 or the antenna module (300) of claim 10;

a motherboard (200) comprising a baseband, BB, processor (220) and a motherboard contact interface (230), corresponding to the DICONI (130, 330), connected to the BB processor (220); and

wherein the flexible printed circuit (100) or the antenna module (300) is releasably connectable to the motherboard (200) by connection of the DICONI (130, 330) to the motherboard contact interface (230).

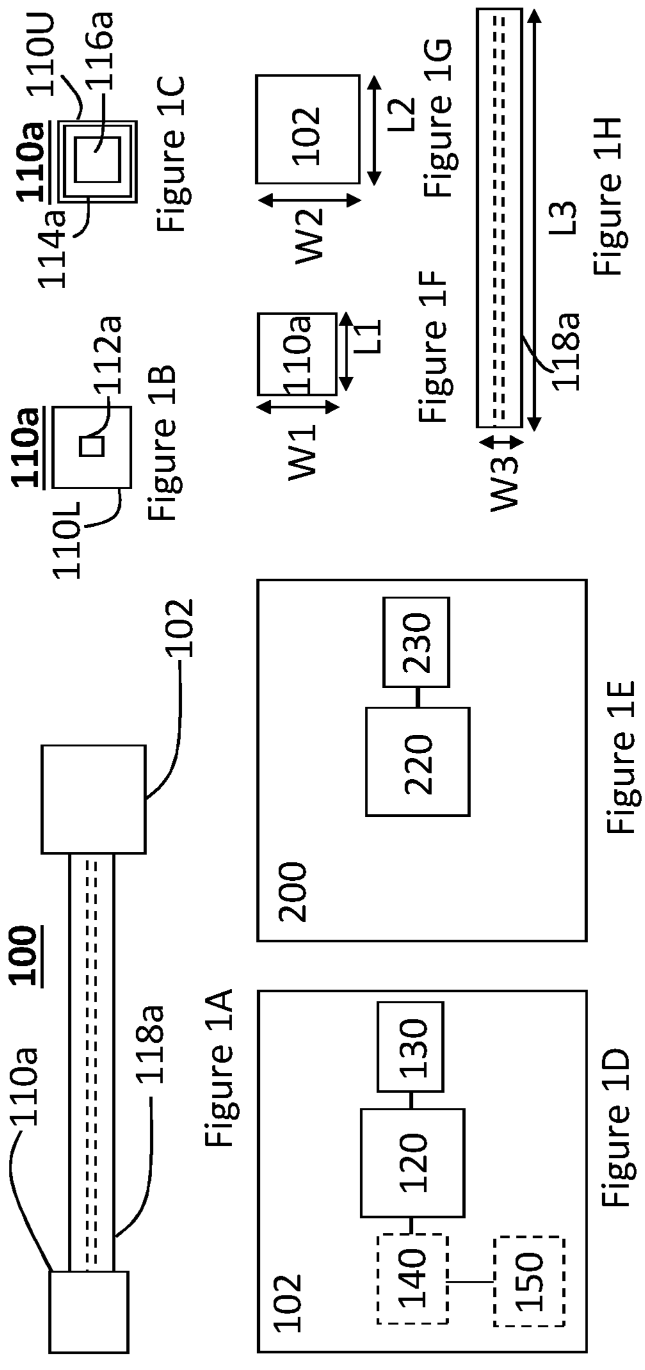


Figure 1A
Figure 1B
Figure 1C
Figure 1D
Figure 1E
Figure 1F
Figure 1G
Figure 1H

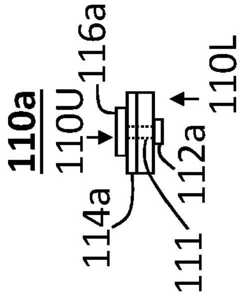


Figure 1I

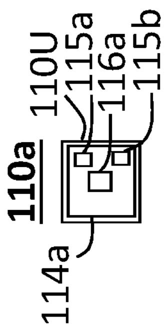


Figure 1J

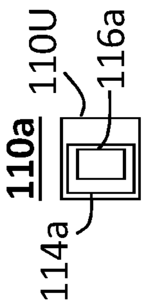


Figure 1K

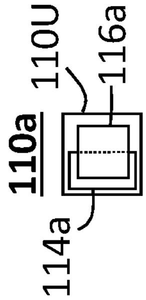


Figure 1L

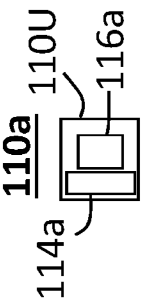


Figure 1M

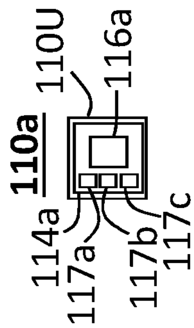


Figure 1N

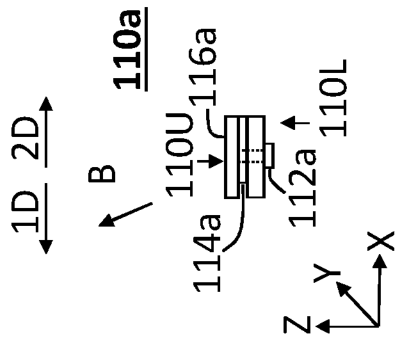


Figure 1Q

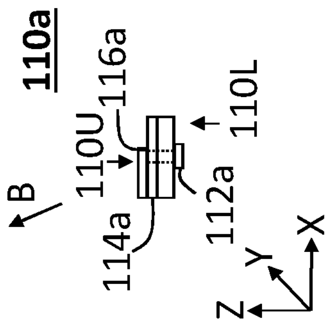


Figure 1P

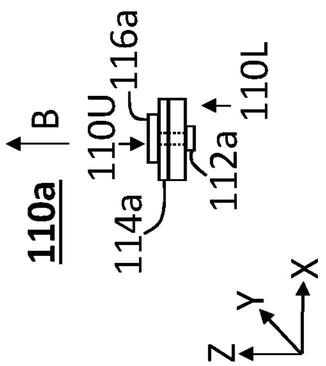
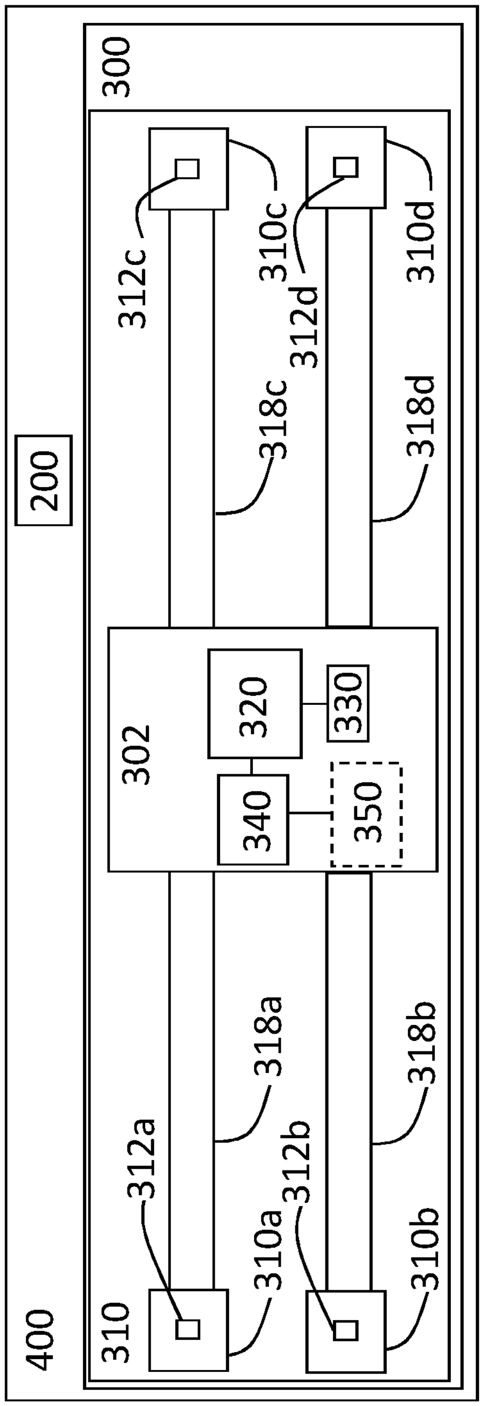


Figure 1O


400
300
200
310
302
320
330
340
350
310a
310b
310c
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312a
312b
312c
312d
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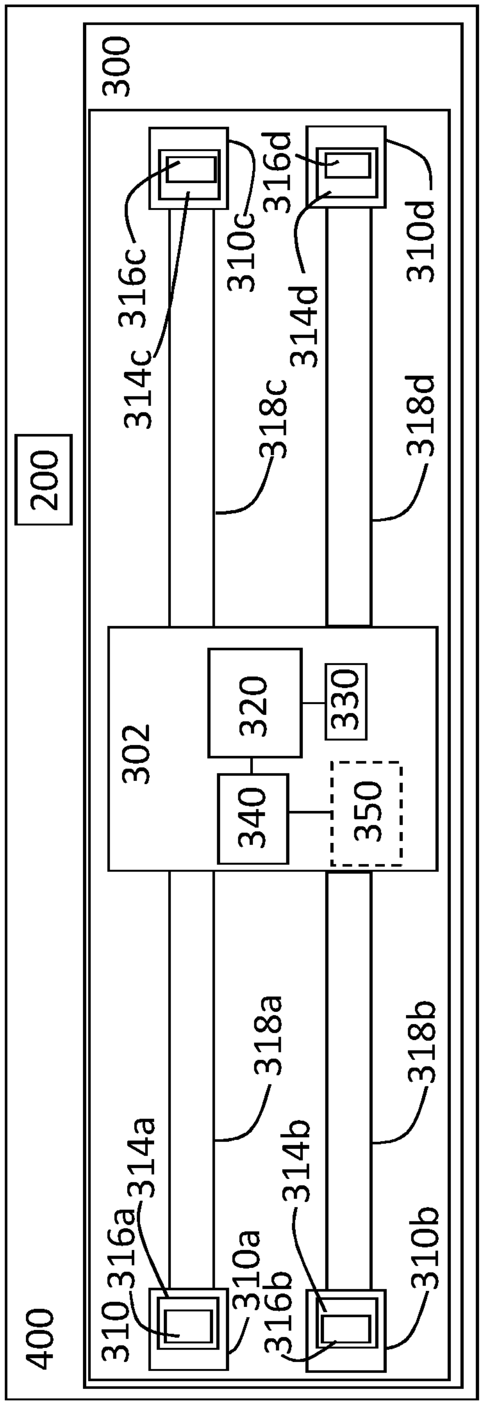
318b
318c
318d

Figure 2A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310b
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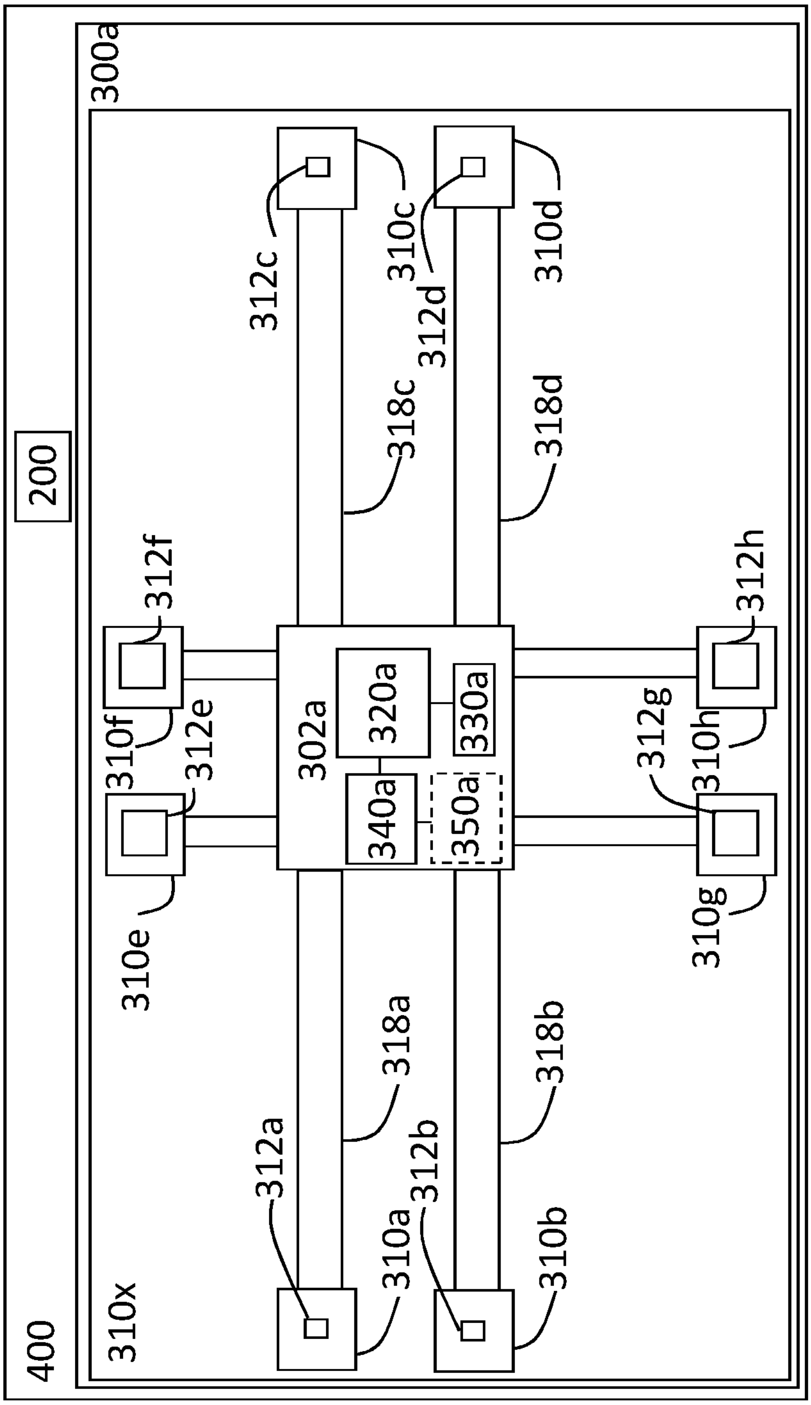
318b
318c
318d

Figure 2B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302a
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340a
350a
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310b
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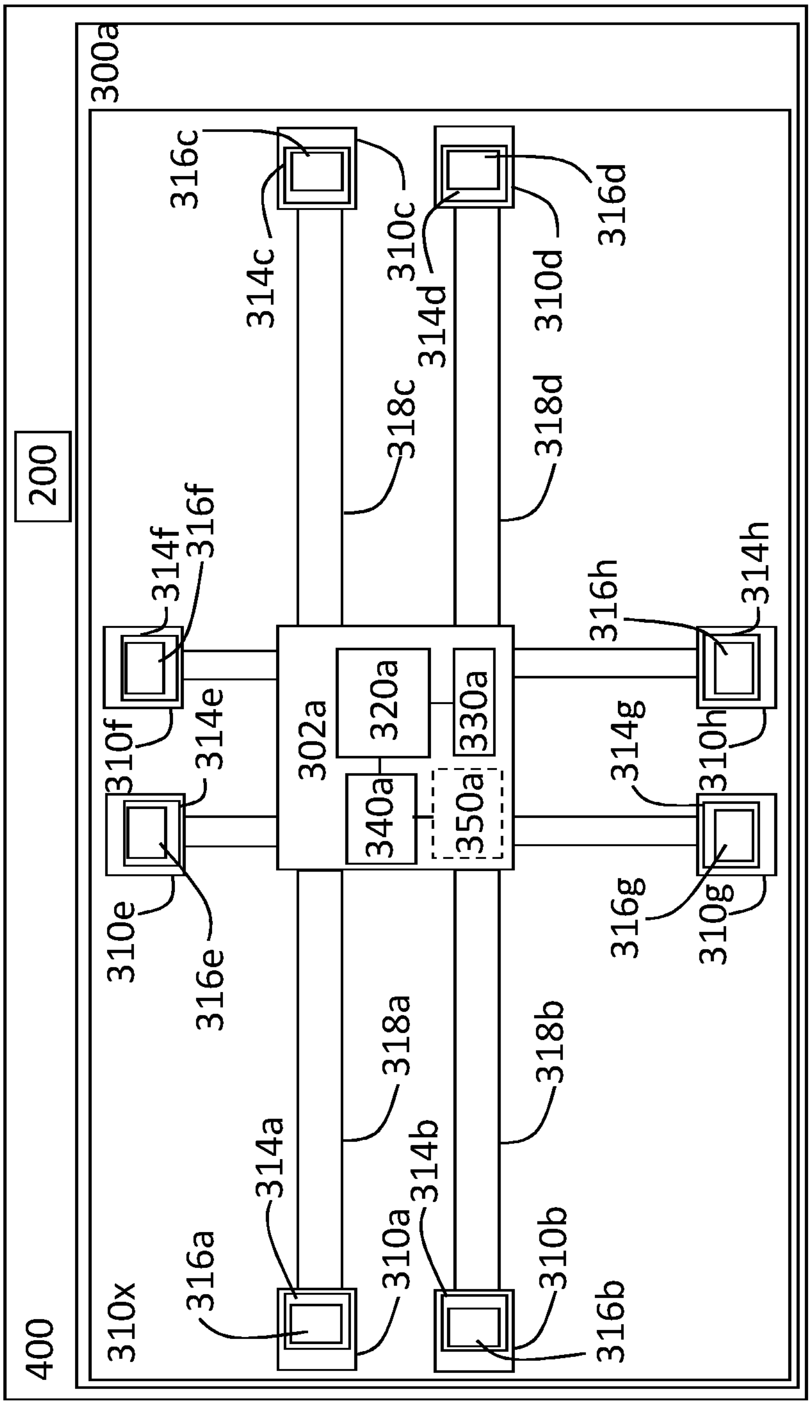
310f
310g
310h
312a
312b
312c
312d
312e
312f
312g
312h
318a
318b
318c
318d

Figure 3A


400
300a
310x
200
302a
320a
330a
340a
350a
310a
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314a
314b
314c
314d
314e
314f
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318a
318b
318c
318d

Figure 3B

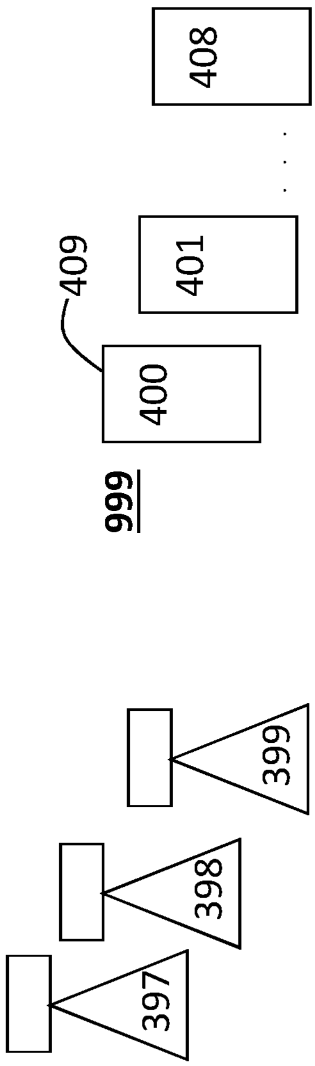

Figure 4

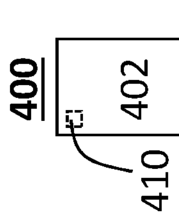

Figure 5A

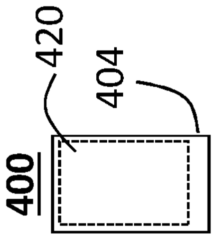

Figure 5B

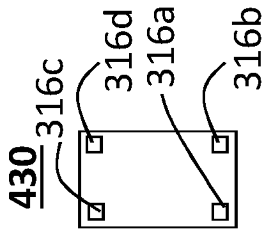

Figure 5C

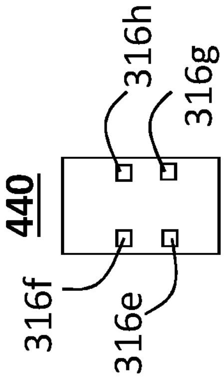

Figure 5D

INTERNATIONAL SEARCH REPORT

International application No
PCT/SE2024/050524

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01Q1/38 H01Q9/04 H01Q19/10
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)
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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 10 347 967 B2 (QUALCOMM INC [US]) 9 July 2019 (2019-07-09) cited in the application	1,6
A	abstract; figures 4-6, 8 column 7, line 10 - column 8, line 4	2-5,7-11
X	US 2022/094773 A1 (LEE JAEWON [KR] ET AL) 24 March 2022 (2022-03-24) abstract; figure 12 paragraphs [0217] - [0227]	1
A	US 11 290 828 B2 (GN HEARING AS [DK]) 29 March 2022 (2022-03-29) abstract; figure 2 column 10, lines 3-56 column 7, lines 19-22	1-11

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 August 2024	21/08/2024

Name and mailing address of the ISA/
European Patent Office, P.B. 5818 Patentlaan 2
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Authorized officer
Hüschelrath, Jens

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/SE2024/050524

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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