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(54) **Title:** DUAL-POLARIZATION ANTENNA ELEMENT, ANTENNA ARRAY AND MULTI-BAND ANTENNA SYSTEM

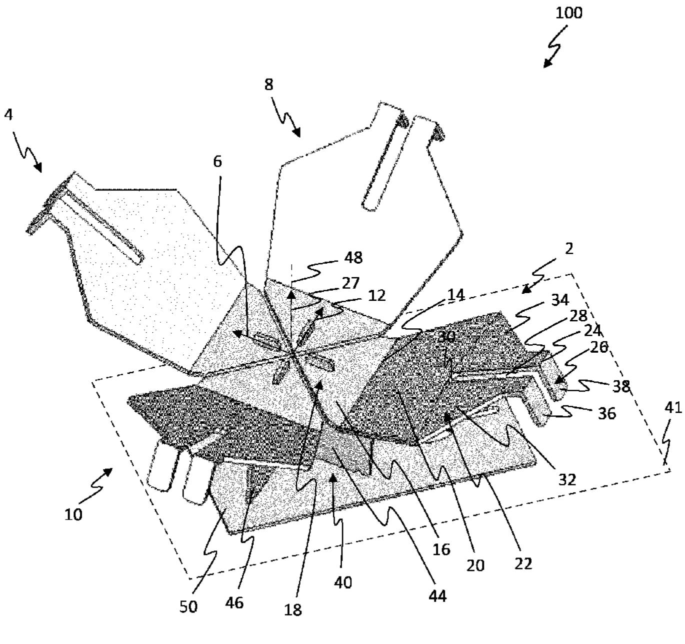

Fig. 1

(57) **Abstract:** A dual-polarization antenna element for an antenna array is disclosed. The antenna element comprises at least one radiator comprising a piece of sheet metal including {i} a feed portion and {ii} a radiation portion comprising a first planar radiation section that is aligned oblique to a main radiation direction of the antenna element, the first planar radiation section configured to extend at least partially at a first height above the reflector surface. The antenna element further comprises a support structure configured to position the feed portion of the at least one radiator at a second height above a reflector surface that is smaller than the first height. An antenna array and a multi-band antenna system are also disclosed.

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Dual-polarization antenna element, antenna array and multi-band antenna system

TECHNICAL FIELD

The present disclosure is directed to a dual-polarization antenna element, an antenna array and a multi-band antenna system.

BACKGROUND

Recent developments in communication technology and ever-increasing requirements of high-speed networks bring about various challenges for antenna elements used for establishing wireless connections.

For example, cellular technology may require multiple antenna arrays, each comprising a plurality of antenna elements, to be installed at a given site to cover a variety of cellular frequency bands. This may result in antenna masts being cluttered with multiple separate antenna arrays housed under respective antenna radomes, thereby also complicating installation and maintenance.

One solution lies in combining multiple antenna arrays supporting different frequency bands under a common antenna radome to reduce the required installation room on an antenna mast.

In this and other scenarios, antenna elements that can be manufactured at low cost and are still highly efficient in their operating environment may be desirable.

SUMMARY

There is a need for a solution that solves one or more of the above or other problems.

According to a first aspect, a dual-polarization antenna element for an antenna array is provided. The antenna element comprises at least one radiator comprising a piece of sheet metal including {i} a feed portion and {ii} a radiation portion comprising a first planar radiation section that is aligned oblique to a main radiation direction of the antenna element. The first planar radiation section is configured to extend at least partially at a first height above the reflector surface. The antenna element further comprises a support structure configured to position the feed portion of the at least one radiator at a second height above a reflector surface which second height is smaller than the first height.

The antenna element may be configured as a directional antenna element. The main radiation direction of the antenna element may be perpendicular to the first polarization direction and perpendicular to the second polarization direction. The main radiation direction of the antenna element may correspond to a direction of a main lobe associated with the antenna element. The main lobe may be associated with electromagnetic radiation emitted by the at least one radiator when the at least one radiator is fed with a feeding signal.

The first planar radiation section may (e.g., be configured to) extend at an acute angle relative to the main radiation direction. The first height may correspond to a maximum height of the first planar radiation section and/or the radiation portion and/or the at least one radiator above the reflector surface. The second height may correspond to a minimum height of the first planar radiation section and/or the radiation portion and/or the at least one radiator above the reflector surface. The first planar radiation section may be configured to extend away from the reflector surface (e.g., and from the feed portion). The first planar radiation section may be configured to extend upwards (e.g., from the feed portion).

The at least one of the radiators may be formed of the piece of sheet metal. The at least one of the radiators may consist of the piece of sheet metal. The piece of sheet metal may be a bent and/or stamped piece of sheet metal. The piece of sheet metal may form only the feed portion and the radiation portion.

The support structure may be configured to position the feed portions of two or more of the at least one radiator at different second heights. That is, the second height may differ between different radiators of the at least one radiator. The antenna element may be configured such that two or more of the at least one radiator are arranged at different heights (e.g., above the reflector surface and/or along the main radiation direction) relative to one another. For example, (e.g., feed sections of) the feed portions and/or (e.g., the first planar radiation sections of) radiation portions of two or more of the at least one radiator may be (e.g., configured to be) arranged at different heights relative to one another (e.g., by the support structure).

The radiator may be configured as a multi-polarization radiator, for example as dual-polarization radiator. The at least one radiator may comprise or consist of a first pair of radiators associated with a first polarization direction and a second pair of radiators associated with a second polarization direction differing from the first polarization direction. The first pair of radiators may be configured as a first dipole (e.g., capable of emitting (e.g., linearly polarized) electromagnetic radiation having the first polarization direction) and the second pair of radiators may be configured as a second dipole (e.g., capable of emitting (e.g., linearly polarized) electromagnetic radiation having the second polarization direction). The radiators of the first pair of radiators may be arranged along the first polarization direction whereas the radiators of the second pair of radiators may be arranged along the second polarization direction. The antenna element may be configured as a cross-polarization antenna element. The first polarization direction may be orthogonal to the second polarization direction.

The support structure may be configured to position the feed portions of the radiators of the first pair at a similar second height and/or the feed portions of the radiators of the second pair at a similar second height. The second height may be specific for the pair of radiators. The second height may differ between the two pairs of radiators.

The first planar radiation sections of two or more of the at least one radiator may extend at least partially at a similar first height. The first height may be similar for two or more of the at least one radiator. Alternatively, or in addition, the first height may differ between two or more of the at least one radiator. The first (e.g., pair-specific) height may differ between the two pairs of radiators. The first planar radiation sections of the radiators of the first pair may be configured to extend (e.g., from the feed portion of the respective radiator) up to the first (e.g., maximum) height and the first planar radiation sections of the radiators of the second pair may be configured to extend (e.g., from the feed portion of the respective radiator) up to another first (e.g., maximum) height. The (e.g., first planar radiation sections of the) radiation portions of the radiators (e.g., the radiators within a pair, or all radiators of the antenna element) may each be configured to extend (e.g., from the feed portion of the respective radiator) a similar distance along a common direction (e.g., the main radiation direction and/or the height direction). For example, the first planar radiation section may be configured to extend from the second height (e.g., the similar distance) to the first height.

The at least one radiator may consist of the feed portion and the radiation portion. The feed portion may comprise or consist of a planar feed section. The entire feed portion may be planar. The (e.g., planar) feed portion and/or the planar feed section may be configured to receive a signal from a feed line and/or transmit a signal to the feed line. The feed line may be electrically connected to the (e.g., planar) feed portion and/or the planar feed section, for example via a soldered or a capacitive connection. For example, the planar feed section is (e.g., be configured to be) aligned oblique to the first planar radiation section and/or perpendicular to the main radiation direction and/or parallel to the reflector surface.

The first planar radiation section of a first one of the at least one radiator may be mirror-symmetrically and/or rotation-symmetrically arranged relative to the first planar radiation section of a second one of the at least one radiator (e.g., a radiator in the same pair of radiators). The (e.g., first planar radiation section and/or feed portion of the) radiators of the antenna element may be rotation-symmetrically arranged relative to one another (e.g., around an axis of symmetry parallel to or corresponding to the main radiation direction of the antenna element). The first planar radiation section of a first one of the at least one of the radiators may be non-parallel to the first planar radiation section of a second one of the at least one of the radiators. For example, all first planar radiation sections of the radiators of the antenna element lie in different, non-parallel planes. Surfaces of the first planar radiation sections of the radiators of a radiator pair may be arranged to face one another. The first planar radiation sections of the radiators of a radiator pair may be arranged to form an angle relative to one another, the angle lying in a plane in which the polarization direction of the radiators of that radiator pair and the main radiation direction of the antenna element are situated. An (e.g., pair-specific) oblique angle between the planar feed section and the first planar radiation section may be similar for the radiators of a radiator pair.

The piece of sheet metal may be bent. The piece of sheet metal may be bent at least along a first (e.g., straight) bending line. The planar feed section and/or the planar feed portion may adjoin (e.g., transition into) the first planar radiation section along the first bending line.

The piece of sheet metal may be bent at least along a second bending line. The radiation portion may comprise a second (e.g., planar) radiation section adjoining the first planar radiation section along the second bending line. The size (e.g., at least one of a length, a width and a surface area) of the second (e.g., planar) radiation section may be smaller than the size of the first planar radiation section. The second bending line may (e.g., be configured to) be located at the first (e.g., maximum) height. The second radiation section may be configured to extend from the first height and/or from the second bending line to a lower height and/or towards the reflector surface. The second radiation section may be aligned (e.g., relative to the first radiation section) such that a required installation space for the antenna element is reduced compared with a scenario in which the second radiation section extends in a same plane as the first planar radiation section. The second radiation section may be aligned perpendicular to the first planar radiation section. The radiation portion may consist of the first planar radiation section and optionally the second (e.g., planar) radiation section.

For example, the radiation portion comprises a slot. The slot may extend in and/or define the polarization direction associated with the at least one of the radiators. The slot may separate a first area of the first planar radiation section from a second area of the first planar radiation section. The slot may separate a third area of the second (e.g., planar) radiation section from a fourth area of the second (e.g., planar) radiation section. In an example, the second (e.g., planar) radiation section is formed by the third area and the fourth area, the third area being spatially separated from the fourth area by the slot. The slot may be inserted by stamping when manufacturing the piece of sheet metal. The slot may have an elongated shape and/or may extend longitudinally.

The support structure may comprise a first planar feed substrate and, optionally, a second planar feed substrate. The planar feed substrate(s) may extend along the main radiation direction of the antenna element and/or (e.g., be configured to extend) perpendicular to the reflector surface and/or perpendicular to at least a part (e.g., the planar feed section) of the feed portion(s). The planar feed section (e.g., of one, two or each of the at least one radiator) may be arranged perpendicular to at least one of the first planar feed substrate and the second planar feed substrate. The first planar feed substrate may be arranged non-parallel to the second planar feed substrate, for example perpendicular thereto. The first planar feed substrate may be attached to the second planar feed substrate. The first planar feed substrate and the second planar feed structure may be slotted together. At least one of the first planar feed substrate and the second planar feed structure may comprise a dielectric base material. For example, at least one of the first planar feed substrate and the second planar feed structure is configured as a printed circuit board (PCB).

The support structure may comprise a feed structure for feeding the at least one radiator with a feeding signal. The feed structure may comprise at least one feed line. One or more of each of the at least one feed line may be configured as a microstrip feedline. The at least one feed line may at least partially (e.g., at least a portion thereof that is to be connected to one of the radiators) extend along the main radiation direction and/or in the height direction. At least one or each of the feed lines may be arranged on the first planar feed substrate and/or the second planar feed substrate.

The first planar feed substrate may be connected to the first pair of radiators and the second planar feed substrate may be connected to the second pair of radiators. The first planar feed substrate may carry at least one feed line for the radiators of the first pair. The first planar feed substrate may comprise or carry impedance matching circuitry such as circuitry configured to provide an impedance transformation matching (e.g., tailored for) the first pair of radiators, and/or a transformation between an asymmetrical and a symmetrical feeding of the first pair of radiators. The second planar feed substrate may carry at least one feed line for the radiators of the second pair. The second planar feed substrate may comprise or carry impedance matching circuitry such as circuitry configured to provide an impedance transformation matching (e.g., tailored for) the second pair of radiators, and/or a transformation between an asymmetrical and a symmetrical feeding of the second pair of radiators. The first planar radiation section of the at least one radiator may be aligned oblique to the (e.g., first or second) planar feed substrate via which the at least one radiator is configured to be fed.

The support structure may further comprise a third planar feed substrate. The first planar feed substrate and the second planar feed substrate may be attached to (e.g., slotted into) the third planar feed substrate. The first planar feed substrate and/or the second planar feed substrate may be arranged perpendicular to the third planar feed substrate. The third planar feed substrate may be specific for the antenna element. The third planar feed substrate may be configured to provide a feed signal exclusively to the radiators of the antenna element comprising said third planar feed substrate. The third planar feed substrate may comprise or carry impedance matching circuitry such as circuitry configured to provide an impedance transformation matching (e.g., tailored for) the antenna element (e.g., one or more of the radiator pairs of said antenna element) and/or a transformation between an asymmetrical and a symmetrical feeding of (e.g., one or more of the radiator pairs of) the antenna element. The third planar feed substrate may be configured to be mounted on a base.

According to a second aspect, an antenna arrangement is provided. The antenna arrangement comprises at least one antenna element according to the first aspect and a reflector having the reflector surface. The reflector surface may be planar. The antenna element may be arranged at a predefined position relative to the reflector and/or be attached to the reflector. The support structure may be attached to the reflector. The antenna arrangement may comprise a base (e.g., relative) to which both the reflector and the support structure are attached.

According to a third aspect, an antenna array is provided. The antenna array comprises a plurality of the antenna elements according to the first aspect. The antenna array may further comprise a reflector having the reflector surface. The reflector surface may be planar. The reflector may be arranged beneath the plurality of antenna elements. The plurality of antenna elements (e.g., the third planar feed substrates and/or the feed portions and/or the support structures thereof) may be arranged at predefined positions relative to the reflector and/or be attached to the reflector. The antenna array may comprise a base (e.g., relative) to which both the reflector and the support structures of the plurality of antenna elements are attached. The antenna array (e.g., each of the antenna elements thereof) may be configured to operate at a single frequency band.

According to a fourth aspect, a multi-band antenna system is provided. The system comprises the antenna array according to the third aspect and at least one additional antenna array, each of the antenna arrays being configured to operate at a different (e.g., array-specific) operating frequency band. The at least one additional antenna array may comprise or consist of a plurality of antenna elements (e.g., according to the first aspect). The antenna elements may differ between the antenna arrays of the system (e.g., in the size of their radiators and/or a bending angle at the respective first bending line). The antenna arrays of the system may be arranged in a common area and/or may overlap one another (e.g., in a view along the main radiation direction of one or more of the antenna elements). The (e.g., radiators of the) antenna elements of the antenna arrays of the system may be interleaved with one another. The radiators of the antenna elements of the antenna array according to the third aspect may be arranged at a different (e.g., first and/or second) height than the radiators of the antenna elements of one or more of the at least one additional antenna array. The first height and/or the second height may differ between antenna elements of different antenna arrays of the multi-band antenna system. Radiators of antenna elements of different antenna arrays of the system may overlap one another at least partially (e.g., in a view along the main radiation direction of one or more of the antenna elements). The radiators of antenna elements of different antenna arrays may be arranged in the form of a stack (e.g., above the reflector surface). Two or more of the antenna arrays may be configured as dual-polarized array (e.g., comprising dual-polarized antenna elements). Polarization directions of antenna elements of different antenna arrays may be similar or parallel or orthogonal to one another.

SHORT DESCRIPTION OF THE FIGURES

Details of the present solution will now be described with reference to the figures, wherein:

Fig. 1 shows a perspective view of an antenna element in accordance with the present disclosure;

Fig. 2 shows an upper view of the antenna element of Fig. 1;

Fig. 3 shows a side view of the antenna element of Fig. 1;

Fig. 4 shows a side view of a variant of the antenna element of Fig. 1;

Fig. 5 shows a perspective view of a multi-band antenna system in accordance with the present disclosure;

Fig. 6 shows an upper view of the system of Fig. 5; and

Fig. 7 shows a side view of the system of Fig. 5.

DETAILED DESCRIPTION

Unless indicated otherwise, the reference signs used in the following denote the same or similar structural or functional features.

Fig. 1-3 show an antenna element 100 in accordance with the present disclosure. The antenna element 100 comprises a first pair of radiators 2, 4 associated with a first polarization direction 6 and a second pair of radiators 8, 10 associated with a second polarization direction 12 orthogonal to the first polarization direction 6. Thus, the antenna element 100 can be referred to as a dual-polarization or cross-polarization antenna element.

The radiators 2, 4, 8, 10 are each made of a piece of sheet metal and have a similar shape, although in other variants differently shaped radiators may be combined in the antenna element 100. The radiators 2, 4 and 8, 10 comprised in a same pair of radiators are arranged in a mirror-symmetrical manner and form a dipole. To avoid repetition, only the radiator 2 will now be described in detail, with the features described for the radiator 2 also applying to the other radiators 4, 8, 10.

The piece of sheet metal forming the radiator 2 is bent along a first bending line 14 that separates a planar feed section 16 of a feed portion 18 of the respective radiator from a first planar radiation section 20 of a radiation portion 22 of the radiator 2. The piece of sheet metal is also bent along a second bending line 24 that separates the first planar radiation section 20 from a second planar radiation section 26 of the radiation portion 22. The feed section 16 extends perpendicular to a main radiation direction 27 of the antenna element 100, whereas the first planar radiation section 20 and the second planar radiation section 26 are each aligned oblique relative to the main radiation direction 27.

The feed portions 18 are configured to be arranged in parallel to a reflector surface 41 of a reflector 42 that, together with the antenna element 100, can be referred to as an antenna arrangement 150. The first planar radiation section 20 of the radiators is bent upwards, away from the feed portion 18 and away from the reflector surface 41, around the first bending line 14. The second planar radiation section 26 of the radiators is bent downwards towards the reflector surface 41 around the second bending line 24.

In the illustrated example, the radiator 2 further comprises a slot 28 extending along the radiation direction 6 associated with the radiator 2 from a distal end of the radiator 2 up to an end point 30 in the first planar radiation section 20, thereby separating areas 32, 34 of the first planar radiation section 20 and also separating areas 36, 38 of the second planar radiation section 26. In another variant, the slot 28 extends in a different manner or is entirely omitted.

The feed portion 18 may have a triangular outline, with one of its corners being arranged adjacent to the symmetry axis 48. The first planar radiation section 20 of the radiation portion 22 may have a varying width (e.g., in a view along the main radiation direction 27 and/or in a view onto the radiation section 20), which is also the case in the example of Fig. 2. The first planar radiation section 20 for example extends from the first bending line 14, where the radiator 2 has a width w1, with a (e.g., linearly) increasing width until a point 39 where the piece of sheet metal forming the radiator 2 has a width w2, and extends from the point 39 with a (e.g., linearly) decreasing width until a point 43 where the radiating portion 22 has a width w3, with w1<w2 and w2>w3 and w3<w1. The width of the second planar radiation section 26 may be constant and corresponds to the width w3 at point 43. Although this may provide a highly efficient radiator, other outlines of the feed portion 18 and the radiation portion 22 are also possible.

The antenna element 100 further comprises a support structure 40 that is configured to position the feed portion 18 of each radiator 2 in a predefined position relative to the reflector surface 41. In this manner, it can be ensured that the first planar radiation section 20 extends at least partially at a first height above the reflector surface that is larger than a second height at which the feed portion 18 of the same radiator 2 is located.

In the illustrated example, the support structure comprises a first planar feed substrate 44 in the form of a PCB that is attached to the first pair of radiators 2, 4, and a second planar feed substrate 46 in the form of another PCB that is attached to the second pair of radiators 8, 10. The two feed substrates 44, 46 are slotted together perpendicularly to one another, such that an intersection line between the two planar feed substrates 44, 46 defines an axis of symmetry 48 relative to which the radiators 2, 4, 8, 10 are arranged in a rotation-symmetrical manner. The feed substrates 44, 46 extend through the feed portions 16 of the respective radiators to attach the respective radiators thereto. Each PCB 44, 46 carries feed lines connected to the respective radiators (e.g., via a solder connection or a capacitive coupling). Impedance matching circuitry and other circuitry may also be provided on one or more of the PCBs 44, 46. The support structure 40 may further comprise a third planar feed substrate 50 arranged parallel to the reflector surface 41 and carrying the first and second planar feed substrates 44, 46. The third planar feed substrate 50 is also formed as a PCB and carries feed lines for feeding the radiators of both pairs of radiators of the antenna element 100. In addition, symmetrical-to-asymmetrical or asymmetrical-to-symmetrical feeding conversion circuitry may be carried by the third planar feed substrate 50. In another variant, the support structure 40 does not comprise planar feed substrates. For example, the support structure may comprise non-planar dielectric support elements such as pillars (e.g., if a coaxial feed line is used for feeding the reflectors).

As shown in Fig. 3, the feed portions 18 of the radiators 2, 4 of the antenna element 100 are positioned by the support structure 40 at similar second heights h1 above the reflector surface 41 and the radiators 2, 4 extend up to a first height m1 above the reflector surface 41. Thus, the radiating portions 22 of the radiators 2, 4 extend for a distance d1=m1-h1 along the main radiation direction 27. The feed portions 18 of the radiators 6, 8 of the antenna element 100 are positioned by the support structure 40 at similar second heights h2 above the reflector surface 41 and the radiators 6, 8 extend up to a first height m2 above the reflector surface 41. Thus, the radiating portions 22 of the radiators 6, 8 extend for a distance d2=m2-h2 along the main radiation direction 27. In the example of Fig. 1, h1=h2 and m1=m2 and d1=d2.

Fig. 4 shows a side view of a variant of the antenna element 100 of Fig. 1. In this variant, the radiators 2, 4 are arranged at a different position along the main radiation direction 27 compared with the radiators 6, 8. In this variant, h1>h2 and m1>m2 and d1=d2. The second height h1, h2 of a radiator may be selected based on a required signal line length of a signal line connected to said radiator and extending along the height direction. For example, the signal lines for the radiators may be arranged on the feed substrates 44, 46 and extend, at least in a connection area 45, 47 of the respective feed substrate, along the height direction (e.g., 27). Thus, by adjusting the height h1, h2 of the feed portion, a length of the associated signal line can be adjusted. In other words, by moving a radiator upwards, the length of the signal line below the radiator becomes larger. Generally speaking, the second heights h1, h2 may be selected to provide a balun for feeding for the radiators of the antenna element 100.

Figs. 5-7 show a multi-band antenna system 200 comprising multiple antenna arrays 300-1, 300-2, 300-3 formed by respective antenna elements 100-1, 100-2, 100-3. The antenna arrays 300-1, 300-2, 300-3 may be arranged under a common antenna radome 52 of the antenna system 200 and/or on a same base 54 of the antenna system 200 and/or above or on the same reflector 42. Each of the antenna arrays 300-1, 300-2, 300-3 is associated with an array-specific frequency band (e.g., a frequency band according to the 4th generation (4G), 5th generation (5G) or 6th

generation (6G) communication standard of the 3rd generation partnership program (3GPP), such as a frequency band with a band number between n1 and n105). In the illustrated example, the antenna array 300-1 is configured to operate at a high frequency band (e.g., having a center operating frequency lying at or between 3.5-7.1 GHz), the antenna array 300-2 is configured to operate at a mid-frequency band (e.g., having a center operating frequency lying at or between 1.4-2.6 GHz) and the antenna array 300-3 is configured to operate at a low frequency band (e.g., having a center operating frequency lying at or between 0.6-0.9 GHz). It is also possible to provide a single-band antenna system that comprises only one of the antenna arrays 300-1, 300-2, 300-3, or a dual-band antenna system that comprises only two of the antenna arrays 300-1, 300-2, 300-3.

The radiators 100-1, 100-2, 100-3 may be scaled versions of one another. The radiators 100-1, 100-2, 100-3 differ from one another not only in the sizes of their radiating portions, but also in their heights h1, h2 and their heights m1, m2 and optionally in their extensions d1, d2 along the main radiation direction 27. One may say that the radiating portions of radiators of different arrays in the example of Figs. 5-7 interleave one another and are arranged in a stacked manner above the radiator surface 41. In another version, the antenna elements may differ between antenna arrays not only in size, but also in type and/or shape, while the antenna elements of at least one of the arrays are configured like the antenna element 100. The radiators 100-3 can be optimized to have a low distortion on the radiators 100-2 and 100-1, and the radiators 100-2 can be optimized to have a low distortion on the radiators 100-1. One may say that the larger radiators (e.g., 100-3) may be configured to be essentially transparent for electromagnetic radiation at the operating frequency of the overlapped smaller radiators (e.g., 100-2 and 100-1). This generally reduces mutual coupling between the radiators of the different antenna arrays.

Especially when deployed in the multi-band antenna system 200, radiators may be highly affected by the environment which may lead to significantly distorting the antenna system performance. Solutions in which radiators are formed as conductive layers on PCBs generally have a lower flexibility in view of retuning the radiator according to the environment. Such PCB-based radiators may also be less efficient compared with solid-metal radiators and may exhibit large variations in their radiation characteristics over their operating frequency band.

The antenna element disclosed herein comprises at least one radiator comprising a piece of sheet metal. This gives the freedom of modifying the radiator shape according to the environment, for example by bending the radiator (e.g., along one or both bending lines) into a desired shape. This may help to improve the performance of the antenna element in the complex array antenna systems such as the system 200. For example, the flexible design may lead to improved antenna performance in a multi-band antenna environment by reducing the near field and mutual coupling effects of the closely spaced radiators. In addition to improving the overall performance of the antenna element, at the same the energy consumption of an antenna system comprising such an antenna element can be reduced. When using planar feed substrates as disclosed herein, a hybrid solution using both PCBs and sheet metal can be provided, which may reduce manufacturing costs.

In other words, the presented antenna element may have a high efficiency due to an all-metal radiator instead of a PCB based radiator. The metal radiators can be easily adjusted by bending to retune the respective radiator according to the environment. The metal radiators can thus be tuned such that effects of a multiband antenna environment can be reduced, specifically the nearfield effects and the mutual coupling between antenna elements. Providing a slot in the radiators may further reduce the coupling between neighboring antenna elements and the environment. Bending the second radiation section downwards may help to increase the electrical length of the radiator due to which wider frequency bandwidth could be achieved with same dipole head dimensions (e.g., a same footprint of the radiators). The antenna element provides stable radiation patterns with less variations over the frequency band compared with PCB-based radiators. The radiators can be placed with some offset in height in order to compensate height difference of two associated balun feeds. In this way a similar performance by both pairs of radiators of the antenna element can be achieved. The antenna element does not require a parasitic capacitive patch. Rather, corresponding compensation can be provided by bending the radiating portion upwards, at the same time tuning the antenna element depending upon the near field effects of the adjacent radiators or environment. The presented solution gives flexibility to implement cross-band interference filtering techniques. Manufacturing costs can be reduced by reducing the number of PCB parts. The solution may also be environment friendly and sustainable due to less amount of energy dissipation in the system and recyclable metal being used for the radiators instead of PCBs. Additional modifications of the solution described herein and further advantages thereof may be apparent to those skilled in the art in view of the present disclosure.

CLAIMS

1. A dual-polarization antenna element (100) for an antenna array (200), the antenna element (100) comprising:

at least one radiator (2, 4, 8, 10) comprising a piece of sheet metal including {i} a feed portion (18) and {ii} a radiation portion (22) comprising a first planar radiation section (20) that is aligned oblique to a main radiation direction (27) of the antenna element (100), the first planar radiation section (20) configured to extend at least partially at a first height (m1; m2) above the reflector surface (41); and

a support structure (40) configured to position the feed portion (18) of the at least one radiator (2, 4, 8, 10) at a second height (h1; h2) above a reflector surface (41) which second height (h1; h2) is smaller than the first height (m1; m2).

2. The antenna element (100) of claim 1, wherein the support structure (40) is configured to position the feed portions (18) of two or more of the at least one radiator (2, 4, 8, 10) at different second heights (h1; h2).

3. The antenna element of claim 1 or 2, wherein the at least one radiator comprises a first pair of radiators (2, 4) associated with a first polarization direction (6) and a second pair of radiators (8, 10) associated with a second polarization direction (12) differing from the first polarization direction (6).

4. The antenna element (100) of claim 3, wherein the support structure (40) is configured to position the feed portions (18) of the radiators (2, 4) of the first pair at a similar second height (h1) and/or the feed portions (18) of the radiators (8, 10) of the second pair at a similar second height (h2).

5. The antenna element (100) of claim 4, wherein the second height (h1; h2) differs between the two pairs of radiators.

6. The antenna element (100) of any one of claims 1 to 5, wherein the first height (m1; m2) corresponds to a maximum height of the first planar radiation section (20) above the reflector surface (41) and differs between radiators of the at least one radiator (2, 4, 8, 10).

7. The antenna element (100) of claim 6 and at least claim 3, wherein the first height (m1; m2) differs between the two pairs of radiators.

8. The antenna element (100) of any one of claims 1 to 7, wherein the piece of sheet metal is bent at least along a first bending line (14) and the feed portion (18) comprises a planar feed section (16) adjoining the first planar radiation (20) section along the first bending line (14).

9. The antenna element (100) of claim 8, wherein the planar feed section (16) is aligned oblique to the first planar radiation section (20) and/or perpendicular to the main radiation direction (27) and/or parallel to the reflector surface (41).

10. The antenna element (100) of any one of claims 1 to 7, wherein the first planar radiation section (20) of a first one of the at least one radiator (2; 8) is mirror-symmetrically and/or rotation-symmetrically arranged relative to the first planar radiation section (20) of a second one of the at least one radiator (4; 10).

11. The antenna element (100) of any one of claims 1 to 10, wherein the piece of sheet metal is bent at least along a second bending line (24) and the radiation portion (22) comprises a second planar radiation section (26) adjoining the first planar radiation section (20) along the second bending line (24).

12. The antenna element (100) of claim 11, wherein the second planar radiation section (26) is configured to extend from the second bending line (24) towards the reflector surface (41).

13. The antenna element (100) of any one of claims 1 to 12, wherein the radiation portion (22) comprises a slot (28).

14. The antenna element (100) of claim 13 and at least claim 3, wherein the slot (28) extends in the polarization direction (6; 12) associated with the at least one of the radiators (2, 4, 8, 10).

15. The antenna element (100) of any one of claims 1 to 14, wherein the support structure (40) comprises a first planar feed substrate (44) and a second planar feed substrate (46) that is arranged perpendicular to the first planar feed substrate (44).

16. The antenna element (100) of claim 15, wherein the first planar feed substrate (44) and the second planar feed structure (46) are slotted together.

17. The antenna element (100) of claim 15 or 16, wherein the first planar feed substrate and the second planar feed substrate (44, 46) extend along the main radiation direction (27) of the antenna element (100) and/or perpendicular to the reflector surface (41) and/or perpendicular to at least a part of the feed portion (18).

18. The antenna element (100) of any one of claims 15 to 17, wherein the support structure (40) further comprises a third planar feed substrate (50), wherein the first planar feed substrate (44) and the second planar feed substrate (46) are connected to the third planar feed substrate (50) and arranged perpendicular to the third planar feed substrate (50).

19. The antenna element (100) of claim 18, wherein the third planar feed substrate (50) is specific for the antenna element (100), the third planar feed substrate (50) comprising circuitry configured to provide an impedance transformation matching the antenna element (100) and/or a transformation between an asymmetrical and a symmetrical feeding of the antenna element (100).

20. An antenna array (300-1, 300-2, 300-3) comprising a plurality of the antenna elements (100) according to any one of claims 1 to 19.

21. A multi-band antenna system (200) comprising:
the antenna array (300-1; 300-2; 300-3) according to claim 20; and
at least one additional antenna array, each of the antenna arrays being configured to operate at a different operating frequency band.

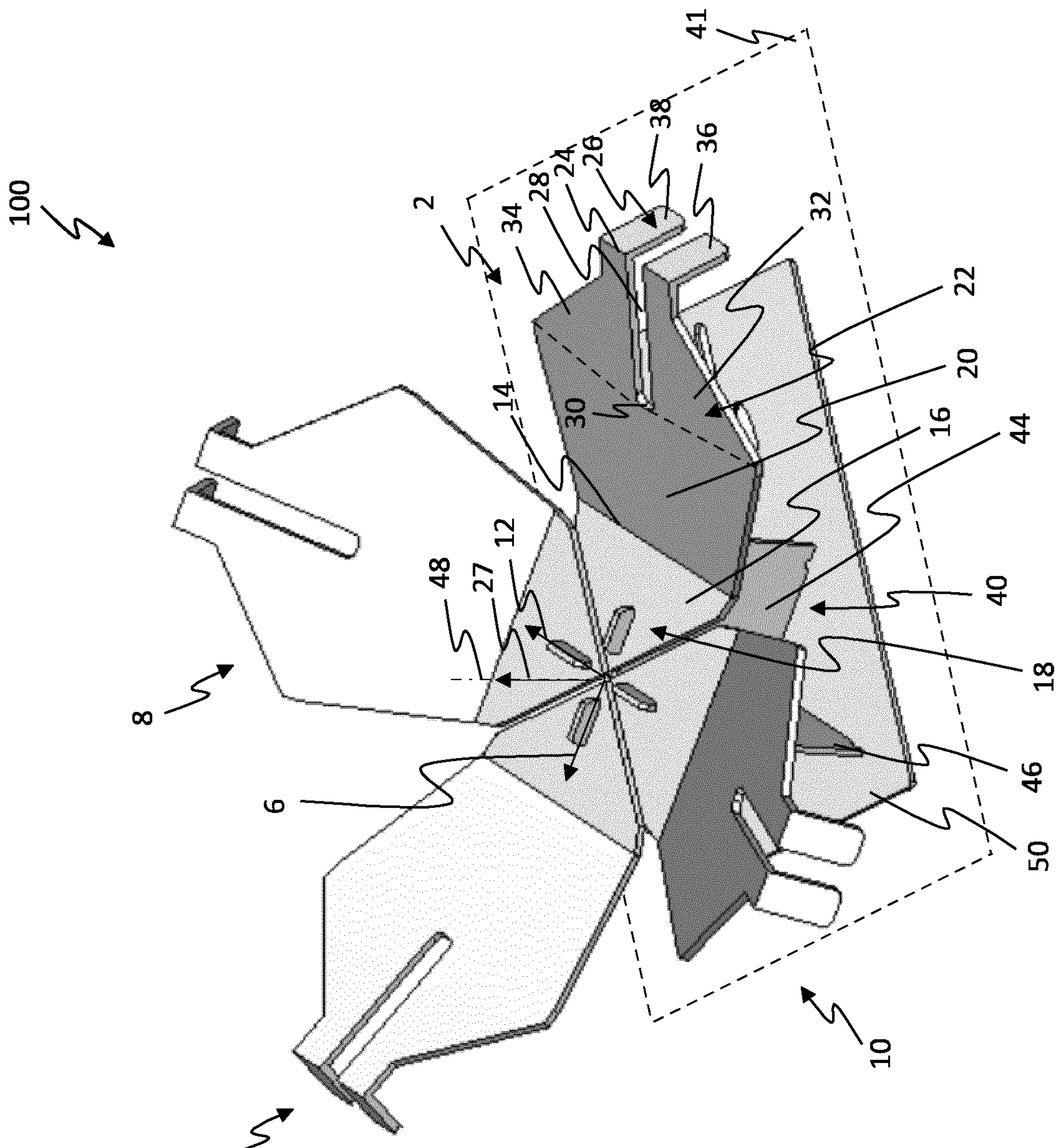
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Fig. 1

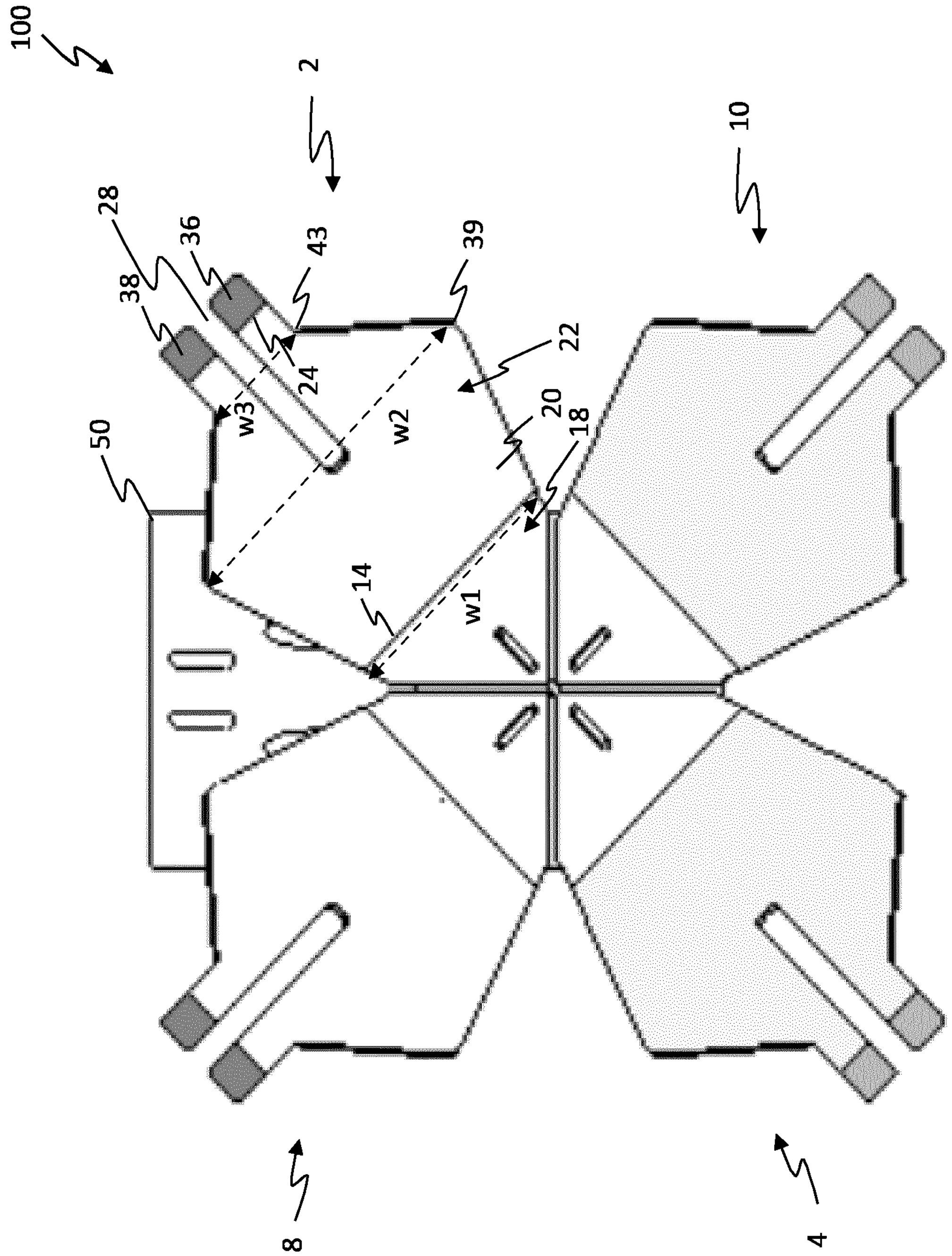
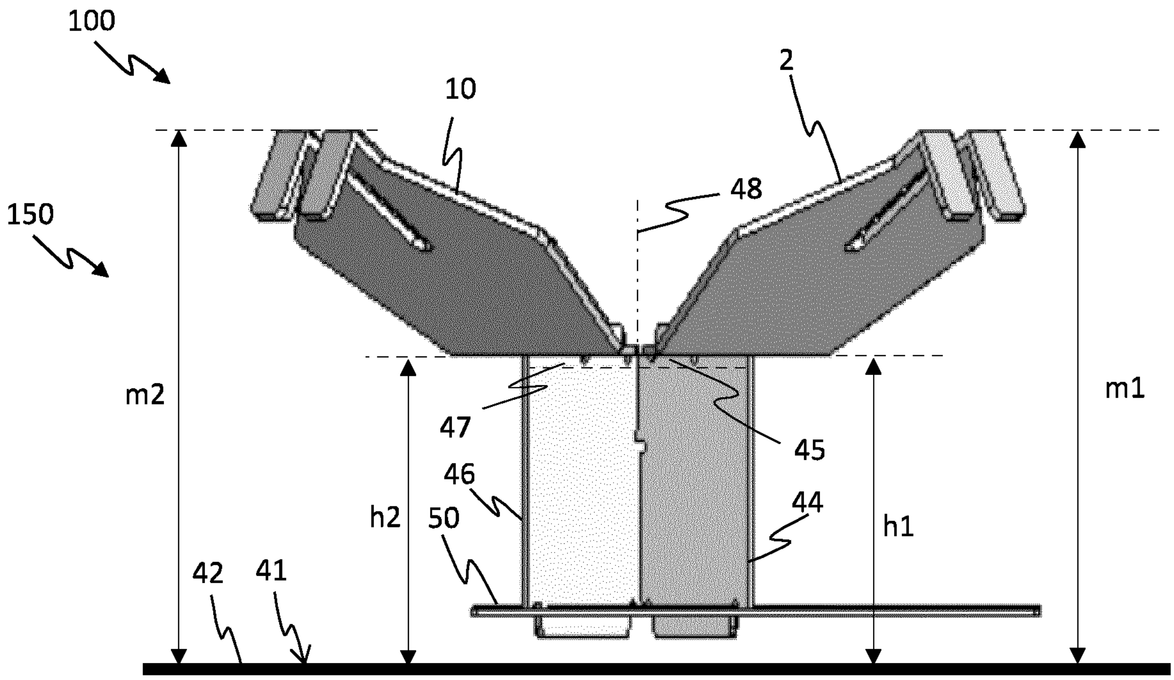


Fig. 2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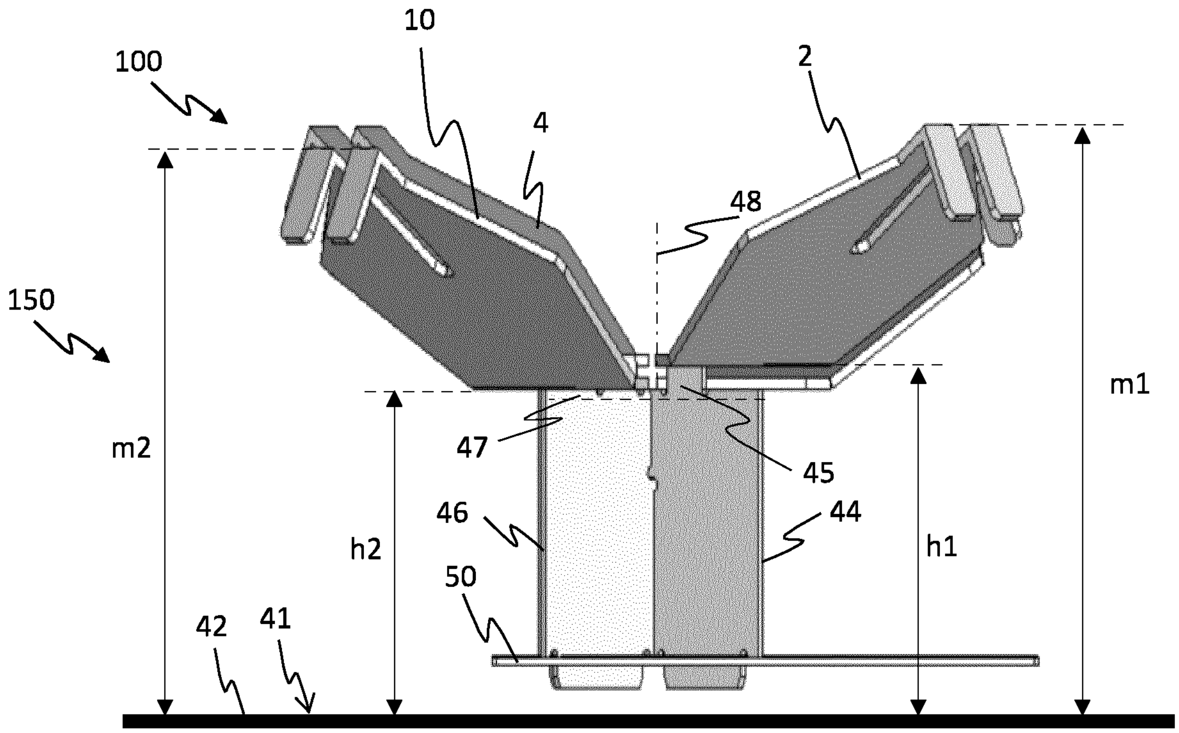
42
41

Fig. 3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m1
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42
41

Fig. 4

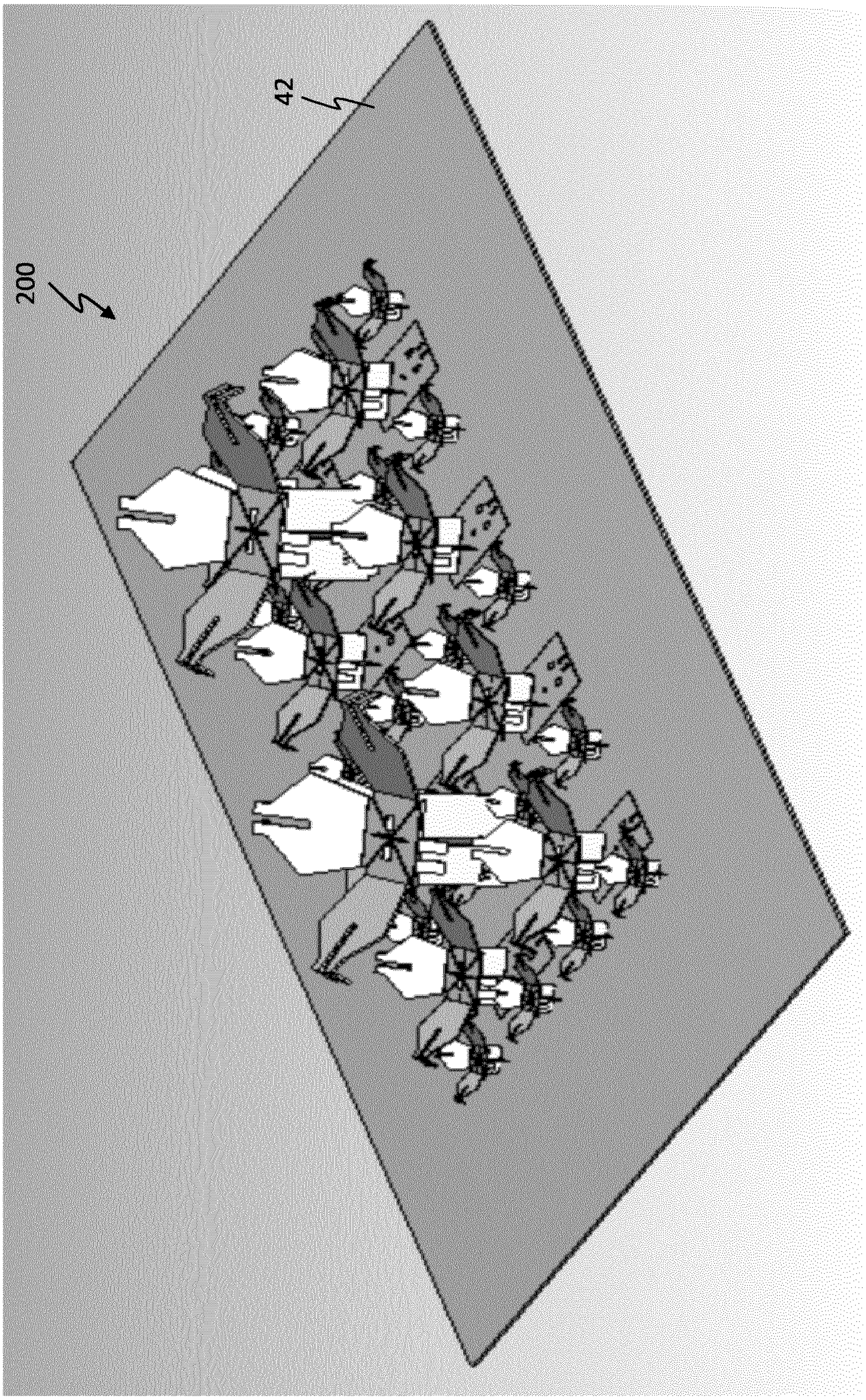

Fig. 5

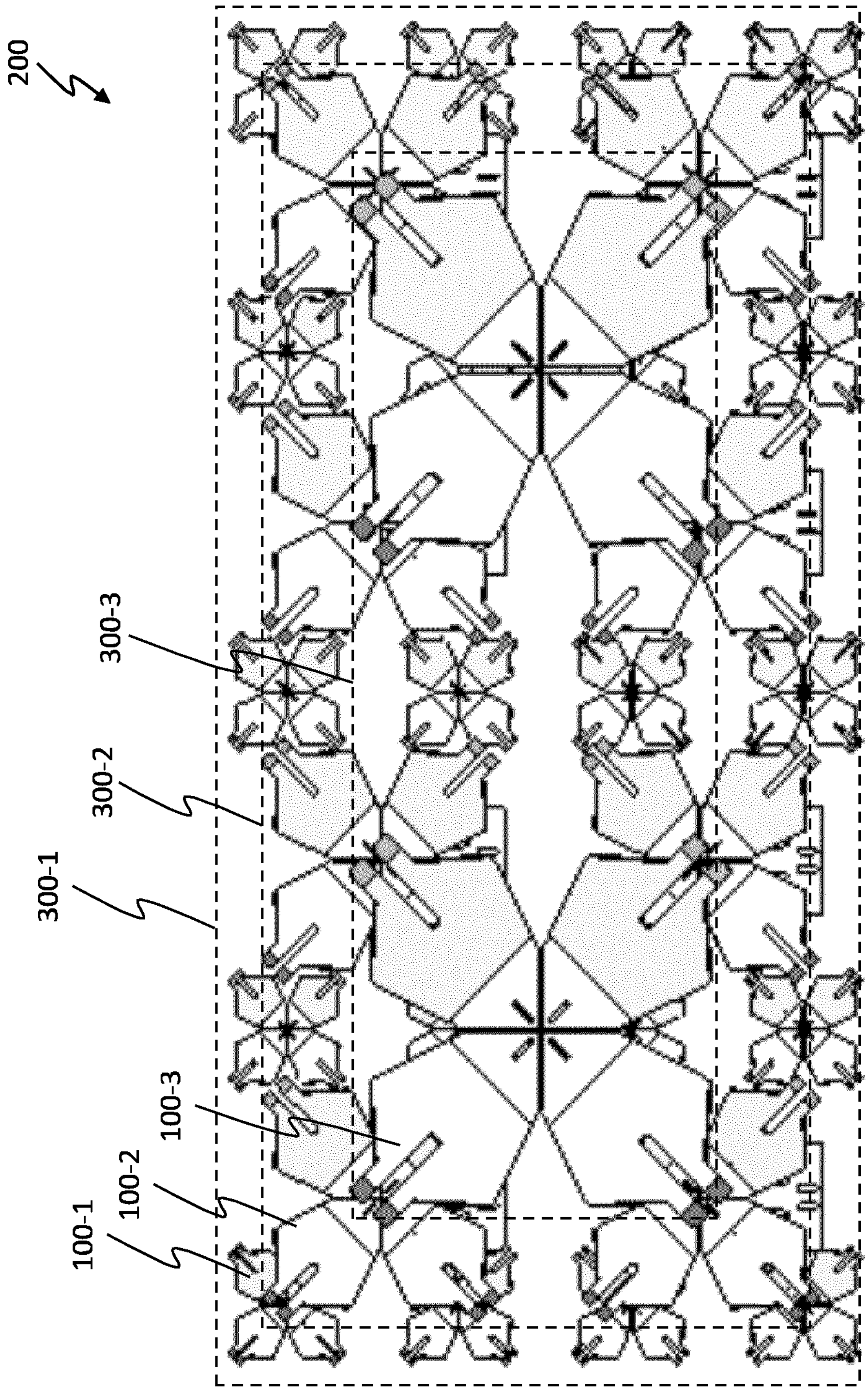

Fig.6

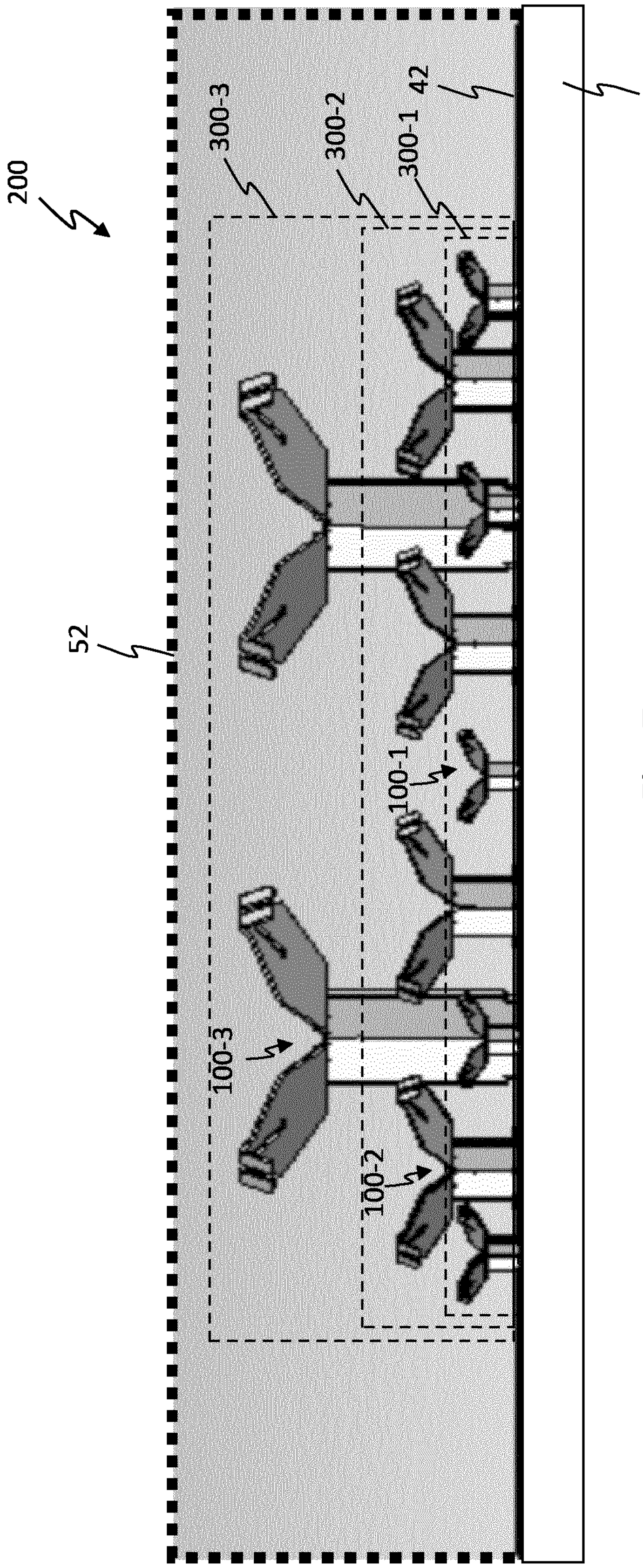

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/078643

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01Q1/24 H01Q1/52 H01Q5/42 H01Q21/24 H01Q21/26
H01Q25/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2017/086855 A1 (GAPWAVES AB [SE]) 26 May 2017 (2017-05-26) page 20 - page 35; figures 5,6,12-15,22 -----	1,3,4, 8-14,20
X	US 2020/212598 A1 (GONZALEZ IGNACIO [DE] ET AL) 2 July 2020 (2020-07-02) paragraph [0085] - paragraph [0124]; figures 2-10,15,20,16 -----	1,3,4,6, 8-13, 15-21
X	US 2016/134023 A1 (LIU PEITAO [CN]) 12 May 2016 (2016-05-12) paragraph [0036] - paragraph [0072]; figures 2-15 -----	1-7,10, 20,21
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[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

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

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 March 2024	03/04/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Sípal, Vít

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Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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International application No

PCT/EP2023/078643

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