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(71) Applicant: **Kaelus Antennas AB**
187 66 Täby (SE)

(72) Inventor: **SOHL, Christian**
187 66 Täby (SE)

(74) Representative: **AWA Sweden AB**
P.O. Box 45086
104 30 Stockholm (SE)

(54) ANTENNA ELEMENT AND ANTENNA COMPRISING ANTENNA ELEMENTS

(57) An antenna element (1) is disclosed, comprising an at least in part conductive carrier substrate (2), at least one pair of first slots (3, 4, 5, 6) arranged in or on the carrier substrate, each first slot (3, 4, 5, 6) of the at least one pair of first slots (3, 4, 5, 6) having at least one associated feed point at the first slot (3, 4, 5, 6), the feed point being arranged to be fed with radio frequency (RF) signals such that RF waves are excited from the first slot (3, 4, 5, 6). The antenna element (1) comprises at least one pair of second slots (7, 8, 9, 10) arranged in or on the carrier substrate (2), wherein each second slot (7, 8, 9, 10) of the at least one pair of second slots (7, 8, 9, 10) acts as a passive (i.e. non-excited) slot. Each slot of the at least one pair of first slots (3, 4, 5, 6) and the at least one pair of second slots (7, 8, 9, 10) extends from a point in or on the carrier substrate (2) to the boundary (14) of the carrier substrate (2). The carrier substrate (2) comprises a first portion (11) and at least one second portion (12, 13), each of the at least one second portion (12, 13) including a part or portion of the boundary (14) of the carrier substrate (2). The first portion (11) of the carrier substrate (2) and each second portion (12, 13) of the carrier substrate (2) are adjoining each other. The first portion (11) of the carrier substrate (2) and each second portion (12, 13) of the carrier substrate (2) are arranged in relation to each other such that for each second portion (12, 13) of the carrier substrate (2), the second portion (12, 13) of the carrier substrate (2) forms an angle relative to the first portion (11) of the carrier substrate (2).

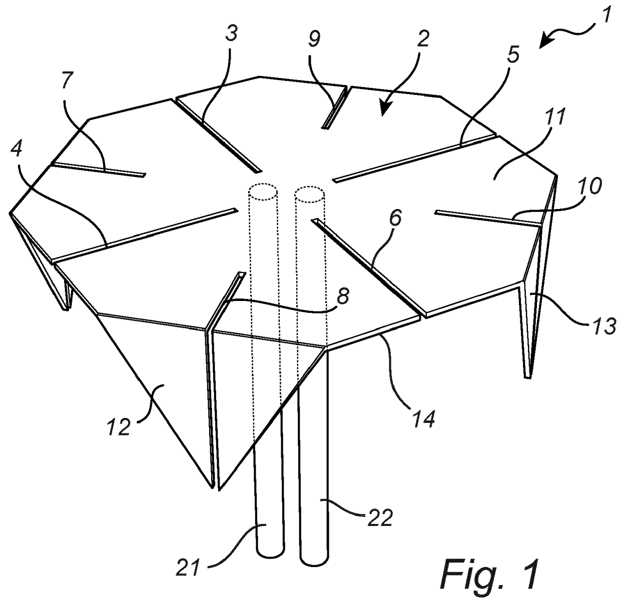

Fig. 1

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Description

TECHNICAL FIELD

[0001] The present invention generally relates to the field of antennas. Specifically, the present invention relates to an antenna element and further to an antenna comprising such antenna elements. The antenna may for example be employed in an antenna unit or antenna array.

BACKGROUND

[0002] Multi-band antenna systems are antenna systems which transmit or receive wireless signals in multiple radio frequency bands. Such antenna systems may for example be used in wireless communication systems such as GSM, GPRS, EDGE, UMTS, HSPA, LTE and/or WiMax. Such antenna systems may include a plurality of antenna elements. The antenna elements may be comprised in or constitute an antenna unit or antenna array and may for example be in the form of discs or plates, or disc-like or plate-like structures. The antenna elements may for example be arranged to provide a desired radiation pattern. A relatively wide bandwidth of such an antenna may be desired in many applications.

SUMMARY

[0003] In view of the foregoing, a concern of the present invention is to facilitate for providing an antenna or antenna element having a relatively wide bandwidth with respect to input impedance and radiation pattern.

[0004] A further concern of the present invention is to facilitate for providing an antenna or antenna element having a relatively small lateral size compared to the longest wavelength of operation.

[0005] To address at least one of these concerns and other concerns, an antenna element in accordance with the independent claim is provided. Preferred embodiments are defined by the dependent claims.

[0006] According to a first aspect, an antenna element is provided. The antenna element comprises an at least in part conductive carrier substrate. The antenna element comprises at least one pair of first slots arranged in or on the carrier substrate. Each first slot of the at least one pair of first slots has at least one associated feed point at the first slot, wherein the feed point is arranged to be fed with radio frequency (RF) signals such that RF waves are excited from the first slot. The antenna element comprises at least one pair of second slots arranged in or on the carrier substrate. Each second slot of the at least one pair of second slots acts as a passive (i.e., non-excited) slot. Each slot of the at least one pair of first slots and the at least one pair of second slots extends from a point in or on the carrier substrate to a boundary of the carrier substrate. The carrier substrate comprises a first portion and at least one second portion. Each of the at least one second portion includes a part or portion of the carrier substrate's boundary. The first portion of the carrier substrate and each second portion of the carrier substrate are adjoining each other. The first portion of the carrier substrate and each second portion of the carrier substrate are arranged in relation to each other such that for each second portion of the carrier substrate, the second portion of the carrier substrate forms an angle relative to the first portion of the carrier substrate. Each second slot of the at least one pair of second slots extends on or in one of the at least one second portion of the carrier substrate.

[0007] The first portion and each second portion may for example be perpendicular to each other, or substantially perpendicular to each other. The first portion of the carrier substrate and each second portion of the carrier substrate may for example be formed from at least one folded, bent and/or curved portion of the carrier substrate, wherein the at least one folded, bent and/or curved portion of the carrier substrate may be arranged so that for each second portion of the carrier substrate, the second portion of the carrier substrate forms an angle relative to the first portion of the carrier substrate. Considering a direction perpendicular or substantially perpendicular to the first portion, each or any second portion may be arranged such that it is folded, bent and/or curved upward or downward with respect to the first portion. The carrier substrate may comprise at least one conductive layer and at least one insulating layer. The at least one folded, bent and/or curved portion of the carrier substrate may be a portion of at least one conductive layer. Any insulating layer which may be on or overlying the portion of at least one conductive layer that is folded, bent and/or curved may be arranged, e.g., deformed, for facilitating the folding, bending and/or curving of the at least one conductive layer. The carrier substrate may for example comprise or be constituted by a printed circuit board (PCB), in which case the non-conductive substrate of the PCB may constitute the insulating layer(s) and may be cut or milled, e.g., along a curve or line, while the conductive part of the PCB may constitute the conductive layer(s) and may be folded, bent and/or curved.

[0008] By way of the first portion and each second portion being arranged in relation to each other such that for each second portion, the second portion forms an angle relative to the first portion, it may be facilitated to achieve a structure of the antenna element such that it has a relatively small extension along a direction perpendicular to a surface normal of the first portion of the carrier substrate. That direction may be referred to as a lateral direction. Thus, the antenna element may have relatively small lateral dimensions compared to its longest wavelength of operation. Further, the first portion and the second portion(s) may be planar, or substantially planar, or flat or substantially flat.

[0009] By the carrier substrate having the first and second portion(s) and with the first portion and each second portion being arranged in relation to each other such that for each second portion, the second portion forms an angle relative to the first portion, the first and second portions can be considered as being integral parts of the carrier substrate.

[0010] The first portion may be considered as a major part of the carrier substrate, and the second portion(s) may be considered as minor part(s) of the carrier substrate.

[0011] In use of the antenna element, an RF signal may be fed to the carrier substrate, wherein RF waves may be excited from the slot(s) of the carrier substrate. Generally, the input impedance, peak gain, radiation beam width, etc. of an antenna element are dependent on its dimensions. By way of at least the second slots having a relatively small width, for example 0.25 mm or less, it may be facilitated to achieve a relatively wide fractional bandwidth over which the antenna element operates satisfactory, while still keeping the lateral size of the antenna element small compared to the longest wavelength of operation.

[0012] Each or any of the slots, e.g., each or any of the first slots and the second slots, may for example be defined as one or more elongated grooves or indentations, or one or more elongated cutouts in the carrier substrate, e.g., in one or more conductive layers of the carrier substrate. In a case where the carrier substrate comprises at least one conductive layer and at least one insulating layer (for example, if the carrier substrate comprises a PCB or the like), each or any of the slots may be formed in one or more conductive layers of the carrier substrate (and may be defined by one or more elongated cutouts, for example), but possibly not in any insulating layer(s).

[0013] For each or any of the slots, e.g., each or any of the first slots and the second slots, the width of the slot may vary along at least a portion of the length of the slot, or even along the entire length of the slot, or the width of slot may be the same (or substantially the same) along the entire (or substantially the entire) length of the slot. In the context of the present application, the width of a slot may be defined as an average width along at least a part or portion of the length of the slot.

[0014] The feed points at the first slots may be arranged to be fed with RF signals and excite the first slots such that the RF waves radiated from the antenna element have wavelengths within a selected wavelength range, which may have a certain center wavelength and corresponding center frequency. A width of each or any of the first slots may be a selected fraction of the center wavelength. A width of each or any of the first slots may for example be about 0.004 times the selected center wavelength. A width of each or any of the first slots may depend on the properties of the carrier substrate that is employed, such as, for example, a permittivity of the carrier substrate. The carrier substrate is preferably constructed such that each or any of the second slots has a relatively small width. Possibly, the carrier substrate may be constructed such that each or any of the second slots has (substantially) the smallest width that can be achieved for the type of carrier substrate and/or the method or technique for manufacturing the carrier substrate that is/are employed. Each or any of the second slots may for example have a width of 0.25 mm or less. Construction of the carrier substrate such that a width of each or any of the second slots is as small as possible may facilitate achieving a decreased lower wavelength limit of operation.

[0015] As indicated in the foregoing, the carrier substrate may for example comprise or be constituted by at least one PCB. In alternative, or in addition, the carrier substrate may comprise or be constituted by at least one flexible circuit structure. The at least one flexible circuit structure may for example comprise at least one flexible foil.

[0016] In the context of the present application, by a slot of an (or the) antenna element acting as a passive slot (which alternatively may be referred to as the slot being a passive slot), which, e.g., each second slot of the at least one pair of second slots may do, it is meant that the slot is not primarily excited. This may entail that the slot acting as a passive slot (such as any of the second slots) does not have at least one associated feed point arranged at the slot, with the feed point being arranged to be fed with RF signals. However, when another slot of the antenna element, which is primarily excited, such as any of the first slots (each of which may have at least one associated feed point at the slot), is fed with RF signals, RF signals may be conveyed via conductive paths and/or reactive electromagnetic fields towards the slot acting as a passive slot, whereby the slot acting as a passive slot may be secondarily excited with RF signals by induced electromagnetic fields. This may apply to each or any slot acting as a passive slot that may be arranged in or on the carrier substrate.

[0017] The first and second slots of the carrier substrate may be arranged in relation to the first portion of the carrier substrate and the second portion(s) of the carrier substrate in different ways.

[0018] For example, each second slot of the at least one pair of second slots may extend on or in one of the at least one second portion of the carrier substrate over to, and on or in, the first portion of the carrier substrate.

[0019] Possibly, each second slot of the at least one pair of second slots may extend only on or in one of the at least one second portion of the carrier substrate, but not on or in the first portion of the carrier substrate.

[0020] Each first slot of the at least one pair of first slots may extend on or in the first portion of the carrier substrate. In alternative, or in addition, each first slot of the at least one pair of first slots may extend on or in one of the at least one second portion of the carrier substrate.

[0021] The antenna element may for example comprise at least two pairs of first slots and at least two pairs of second slots. The arrangement of the first slots of the pairs of first slots and the second slots of the pairs of second slots in or on the carrier substrate, respectively, may be mirror symmetric with respect to each of two mutually perpendicular symmetry planes through a center point of the carrier substrate as seen from above. Such a configuration of first slots and second slots in the antenna element may facilitate for two orthogonal polarizations in the far field region. The pairs of first slots in the antenna element are fed independently of each other. By arranging the first slots of the pairs of first slots and the second slots of the pairs of second slots in or on the carrier substrate, symmetrically with respect to each of two mutually perpendicular symmetry planes through a center point of the carrier substrate as seen from above, isolation between the two orthogonal polarizations of the antenna element may be increased. For each or any pair of first slots in the antenna element, the first slots of the pair of first slots may be fed with the same, or substantially the same, phase values. Feeding the first slots of a pair of first slots with the same, or substantially the same phase values, may facilitate or allow for achieving constructive interference of RF waves excited from the first slots of that pair of first slots, at least in a direction parallel to or coinciding with the antenna element boresight (which may be in a direction parallel to or coinciding with a surface normal of the first portion of the carrier substrate). Each or any pair of first slots may be fed by means of a feed network, which may be configured to transport RF signals to the feed points. The feed network will be described further in the following.

[0022] The carrier substrate may for example comprise at least one conductive layer and at least one insulating layer. The at least one folded, bent and/or curved portion of the carrier substrate may be arranged so that the at least one conductive layer in the first portion of the carrier substrate and the at least one conductive layer in each second portion of the carrier substrate are galvanically adjoined.

[0023] The first portion of the carrier substrate and each second portion of the carrier substrate may be formed from at least one portion of the carrier substrate that is folded, bent and/or curved along at least one line on the carrier substrate. Each of the at least one line may be either straight or curved.

[0024] The carrier substrate may for example comprise at least one conductive layer and at least one insulating layer. Possibly, each slot of the at least one pair of first slots and/or each slot of the at least one pair of second slots may be formed in at least one conductive layer of the carrier substrate, but not in any insulating layer of the carrier substrate. Alternatively, each slot of the at least one pair of first slots and/or each slot of the at least one pair of second slots may be formed in at least one conductive layer of the carrier substrate and in at least one insulating layer of the carrier substrate. Particularly in case a slot of the at least one pair of first slots and/or each slot of the at least one pair of second slots is formed in at least one conductive layer of the carrier substrate and in at least one insulating layer of the carrier substrate, the slot may be metallized to increase capacitance between opposite edges of the slot. For example, each slot of the at least one pair of first slots and/or each slot of the at least one pair of second slots may be metallized to increase capacitance between opposite edges of the slot. Metallizing a slot may entail coating a metal or a conductive material on the two opposite edges of the slot. This may decrease the lower frequency of operation of the antenna element, or, alternatively, make it easier to produce the carrier substrate for a given lower frequency limit in case the width of the slot should be relatively small. The slot's width could be metallized along a portion of the length of the slot, or even along the entire (or substantially the entire) length of the slot. The antenna element may be configured such that the RF waves radiated from the antenna element have wavelengths within a certain wavelength range. Metallizing one or more slot(s) of the carrier substrate may facilitate achieving a decreased lower limit of that wavelength range. In alternative, or in addition, forming and metallizing a slot of the carrier substrate may entail forming one or more vias or through-holes in the carrier substrate, and metallizing the via(s) or through-hole(s).

[0025] As mentioned previously, the carrier substrate may for example comprise or be constituted by a PCB. The non-conductive substrate(s) of the PCB may constitute the insulating layer(s), and may for example be cut or milled, e.g., along a curve or line, while the conductive part(s) of the PCB may constitute the conductive layer(s).

[0026] In alternative or in addition, the carrier substrate may comprise a plate, which for example may be made of metal or another conductive material. Each or any slots of the carrier substrate (e.g., the first slots and/or the second slots) may for example be formed by means of a laser cutting or milling process. A PCB might be attached to the plate, e.g., by means of gluing or some other similar adhesive technique, to facilitate feeding the first slots (each of which may have at least one associated feed point arranged at the slot) with RF signals. The PCB attached to the plate may hence act as or be part of a feed network for feeding the first slots.

[0027] As mentioned previously, the carrier substrate may comprise at least one conductive layer and at least one insulating layer. The antenna element may comprise at least one pair of cavities or recesses in at least one conductive layer of the carrier substrate. Each pair of cavities or recesses may be associated with a pair of first slots or a pair of second slots. Each slot of the pair of first slots or the pair of second slots may extend from a boundary of one of the pair of cavities or recesses in the carrier substrate to the boundary of the carrier substrate.

[0028] For example, the antenna element may comprise at least two pairs of cavities or recesses. The arrangement of the cavities or recesses of the pairs of cavities or recesses may be mirror symmetric with respect to each of two mutually perpendicular symmetry planes through a center point of the carrier substrate as seen from above.

[0029] Each or any cavity or recess of the at least one pair of cavities or recesses may for example have a shape that as seen from above is circular, square, rectangular, rhombic, rhomboidal, or parallelogrammatic. However, other shapes are also possible. The shape of a cavity or recess of the antenna element may be the same or different from the shape of one or more other cavities or recesses of the antenna element.

[0030] The first portion of the carrier substrate and/or each or any of the at least one second portion of the carrier substrate may be planar, or substantially planar.

[0031] The carrier substrate may comprise a plurality of second portions.

[0032] Each or any second slot of the at least one pair of second slots (which act as passive slots) may for example have a width that is 0.25 mm or less.

[0033] The feed points may be connected to a feed network of the antenna element. The feed network may be configured to transport RF signals to the feed points. The antenna element may comprise at least one stub connected to the feed network. Each or any of the at least one stub may be connected at one end thereof (possibly at only one end thereof) to the feed network and may have one end that is not connected to the feed network or any other component. The latter end may be referred to as a free end. The free end of each or any of the at least one stub may be open-circuited or short-circuited. Each or any of the at least one stub may for example comprise in principle any type(s) of transmission line(s).

[0034] The feed network may include all components necessary to feed the antenna element with RF signals having appropriate amplitude and phase values. The feed network may for example include one or more coaxial transmission lines, microstrip lines and/or other types of transmission lines. A person skilled in the art will recognize that the feed network may be implemented or realized in different ways and detailed description of the feed network herein is therefore omitted.

[0035] The antenna element may comprise at least one at least in part conductive, parasitic patch, which may be arranged at a distance from the carrier substrate. The parasitic patch may be referred to as a parasitic element.

[0036] Each or any of the at least in part conductive parasitic patch(es) may for example be arranged at a distance from the carrier substrate by means of one or more dielectric supports or the like, which may be arranged intermediate the carrier substrate and each or any of the at least in part conductive parasitic patch(es).

[0037] Each or any of the at least in part conductive parasitic patch(es) may be constituted by a solid body, or it may be non-solid, e.g., having one or more holes, slots, etc.

[0038] In case there are several parasitic patches, the parasitic patches may for example be arranged (e.g., stacked) one above the other, with a selected distance between different parasitic patches, and/or the parasitic patches may be arranged side by side.

[0039] Each or any of the at least in part conductive parasitic patch(es) may be relatively large, e.g., so as to cover an antenna element arranged beneath it as seen from above the patch(es), or relatively small, e.g., such that an antenna element arranged beneath it is partly visible as seen from above the patch(es).

[0040] Each or any of the at least in part conductive parasitic patch(es) may have a shape that as seen from above the patch(es) is for example circular, square, rectangular, rhombic, rhomboidal, or parallelogrammatic. In case there are several parasitic patches, at least some parasitic patches may have different shape. Possibly, at least some parasitic patches may have the same shape.

[0041] Each or any of the at least in part conductive parasitic patch(es) may be planar, but this is not required, and other shapes or curvatures of the parasitic patch(es) are contemplated.

[0042] At least one of the at least one second portion of the carrier substrate may comprise at least two different portions. At least two of the different portions may be adjoining each other and may be arranged at an angle with respect to each other. The at least two of the different portions may for example be formed from at least one folded, bent and/or curved portion of the carrier substrate. By way of such at least two different portions of a second portion of the carrier substrate, it may be further facilitated to achieve a structure of the antenna element such that it has relatively small lateral dimensions compared to the longest wavelength of operation.

[0043] According to a second aspect, an antenna is provided. The antenna according to the second aspect comprises a plurality of antenna elements according to the first aspect, and at least one at least in part conductive reflector. At least the carrier substrate of each of the antenna elements is arranged at a distance from the at least one reflector and at a distance from the other antenna element(s). Thus, the carrier substrate of each of the antenna elements may be arranged at a distance from the carrier substrate of the other antenna element(s).

[0044] Possibly, at least some, or all, of the antenna elements may be arranged at one side of the at least one reflector. For example, the at least one reflector may have a shape of a plate or disc, and at least some, or all, of the antenna elements may be arranged at one side thereof.

[0045] Possibly, at least some, or all, of the antenna elements may be arranged at the same distance from the at least one reflector. The antenna elements may for example be arranged to form an array of antenna elements. The array of antenna elements may be regular or irregular. The array of antenna elements must not necessarily be linear, with the antenna elements being arranged in a succession along an axis (although it may be), and may be confined in a plane. The at least one reflector may define an acting ground plane for the antenna elements. The at least one reflector may serve as a reflecting structure for RF waves radiated from each or any of the plurality of antenna elements.

[0046] As described in the foregoing, by way of the configuration of the antenna element according to the first aspect, it may be facilitated to achieve a relatively large fractional bandwidth over which the antenna element operates satisfactory, while still keeping the lateral size of the antenna element relatively small compared to the longest wavelength of operation. This may facilitate positioning the antenna elements in the antenna according to the second aspect relatively close, while still achieving a relatively large fractional bandwidth over which the antenna according to the second aspect may operate satisfactory. Thereby, the antenna according to the second aspect may be made relatively compact in size, and it may hence only require a relatively small space for installing it in a desired or required space.

[0047] The plurality of antenna elements in the antenna according to the second aspect may for example be arranged in an array, which for example may be linear (with the antenna elements being arranged in a succession along an axis), or two-dimensional (e.g., with the antenna elements being arranged along two orthogonal axes). The distances between adjacent antenna elements along an axis in the array may for example be the same. In a two-dimensional array, the distance between adjacent antenna elements along one of the two orthogonal axes may be different from the distance between adjacent antenna elements along the other one of the axes.

[0048] According to a third aspect an antenna is provided. The antenna according to the third aspect comprises a plurality of antenna elements according to the first aspect. At least the carrier substrate of each of the antenna elements is arranged at a distance from the other antenna element(s).

[0049] For each or any antenna element of the plurality of antenna elements in the antenna according to the second aspect or the third aspect, the feed points at the first slots may be arranged to be fed with RF signals and excite the first slots such that the RF waves radiated from the antenna element have wavelengths within a selected wavelength range. The selected wavelength range for one antenna element may differ from the selected wavelength range for at least one of the other antenna element(s). In alternative, or in addition, a center operating frequency of the selected wavelength range for one antenna element may differ from a center operating frequency of the selected wavelength range for at least one of the other antenna element(s). Thus, the antenna elements in the antenna according to the second aspect or the third aspect must not necessarily be the same with respect to frequency/frequencies of RF waves radiated therefrom (but they could be). For example, the antenna could comprise a succession of antenna elements, where each of the antenna elements is in accordance with the first aspect. Every other antenna element in the succession could be configured such that the RF waves radiated from the antenna element have wavelengths within a first wavelength range, and each of the other antenna elements in the succession could be configured such that the RF waves radiated from the antenna element have wavelengths within a second wavelength range, different from the first wavelength range. The second wavelength range could for example be narrower than the first wavelength range.

[0050] Some, or all, of the antenna elements of the plurality of antenna elements in the antenna according to the third aspect may for example be arranged one over the other, e.g., so as to form a stack of antenna elements.

[0051] For example, the antenna according to the third aspect may comprise at least a first antenna element and a second antenna element, wherein the carrier substrate of the second antenna element is arranged above the carrier substrate of the first antenna element. The first antenna element could be configured such that the RF waves radiated from the first antenna element have wavelengths within a first wavelength range, and the second antenna element could be configured such that the RF waves radiated from the second antenna element have wavelengths within a second wavelength range, different from the first wavelength range. The second wavelength range could for example be narrower than the first wavelength range. By providing such a first antenna element and second antenna element in the antenna according to the third aspect, the antenna according to the third aspect may be comprised in or constitute a dual-band antenna. Possibly, each of the first antenna element and the second antenna element may comprise an at least in part conductive parasitic patch (e.g., such as described in the foregoing), which may be arranged at a distance from the carrier substrate of the first antenna element and the second antenna element. The parasitic patch of the first antenna element may act as a reflector for the second antenna element, or the carrier substrate of the second antenna element. An at least in part conductive reflector may be arranged beneath, and at a distance from, at least the carrier substrate of the first antenna element.

[0052] Further objects and advantages of the present invention are described in the following by means of exemplifying embodiments. It is noted that the present invention relates to all possible combinations of features recited in the claims. Further features of, and advantages with, the present invention will become apparent when studying the appended claims and the description herein. Those skilled in the art realize that different features of the present invention can be combined to create embodiments other than those described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0053] Exemplifying embodiments of the invention will be described below with reference to the accompanying drawings.

Figures 1 to 11 are schematic views of an antenna element according to one or more embodiments of the present invention.

Figures 12 to 15 are schematic views from the above of a parasitic patch in accordance with one or more embodiments of the present invention.

Figures 16 to 18 are schematic views from the above of a portion of a carrier substrate of an antenna element in accordance with one or more embodiments of the present invention.

Figures 19 and 20 are schematic perspective views of an antenna according to one or more embodiments of the present invention.

Figures 21 and 22 are schematic views of an antenna element according to one or more embodiments of the present invention.

[0054] All the figures are schematic, not necessarily to scale, and generally only show parts which are necessary in order to elucidate embodiments of the present invention, wherein other parts may be omitted or merely suggested.

DETAILED DESCRIPTION

[0055] The present invention will now be described hereinafter with reference to the accompanying drawings, in which exemplifying embodiments of the present invention are shown. The present invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments of the present invention set forth herein; rather, these embodiments are provided by way of example so that this disclosure will convey the scope of the present invention to those skilled in the art.

[0056] Figure 1 is a schematic perspective view of an antenna element 1 according to one or more embodiments of the present invention. The antenna element 1 comprises an at least in part conductive carrier substrate 2. The carrier substrate 2 may for example comprise at least one conductive layer and at least one insulating layer. The carrier substrate 2 may for example comprise or be constituted by a printed circuit board (PCB). In alternative, or in addition, the carrier substrate 2 could for example comprise or be constituted by at least one flexible circuit structure, which for example may comprise one or more flexible foils.

[0057] The antenna element 1 comprises at least one pair of first slots arranged in or on the carrier substrate 2. In accordance with the embodiment of the present invention illustrated in Figure 1, the antenna element 1 comprises two pairs of first slots, 3 and 6, and 4 and 5, respectively, arranged in or on the carrier substrate 2. The slots of each pair of first slots 3, 4, 5, 6 may be arranged opposite to each other, as illustrated in Figure 1 (or substantially opposite to each other).

[0058] Each first slot 3, 4, 5, 6 of the at least one pair (e.g., two pairs) of first slots 3, 4, 5, 6 has at least one associated feed point (not illustrated in Figure 1) arranged at the first slot 3, 4, 5, 6. The feed point(s) associated with each first slot 3, 4, 5, 6 is/are arranged to be fed with radio frequency (RF) signals such that RF waves are excited from the first slot 3, 4, 5,6.

[0059] The antenna element 1 comprises at least one pair of second slots arranged in or on the carrier substrate 2. In accordance with the embodiment of the present invention illustrated in Figure 1, the antenna element 1 comprises two pairs of second slots, 7 and 10, and 8 and 9, respectively, arranged in or on the carrier substrate 2. The slots of each pair of second slots may be arranged opposite to each other, as illustrated in Figure 1 (or substantially opposite to each other).

[0060] Each second slot 7, 8, 9, 10 of the at least one pair (e.g., two pairs) of second slots 7, 8, 9, 10 acts as a passive (i.e., non-excited) slot. As illustrated in Figure 1, each slot of the at least one pair (e.g., two pairs) of first slots 3, 4, 5, 6 and the at least one pair (e.g., two pairs) of second slots 7, 8, 9, 10 extends from a point in or on the carrier substrate 2 to the boundary 14 of the carrier substrate 2.

[0061] Each or any second slot 7, 8, 9, 10 of the at least one pair of second slots (which act as passive slots) may for example have a width that is 0.25 mm or less. Each or any first slot 3, 4, 5, 6 of the at least one pair of first slots may have a width that is larger than the width of the second slots 7, 8, 9, 10.

[0062] In accordance with each of the illustrated embodiments of the present invention, including those illustrated in Figures 1 to 8, the carrier substrate 2 comprises at least one conductive layer and at least one insulating layer. To that end, the carrier substrate 2 may for example comprise one or more PCBs or the like. Each of the first slots and the second slots of the carrier substrate 2 is formed in one or more conductive layers of the carrier substrate 2, but not in the insulating layer(s) of the carrier substrate 2, and comprises an elongated cutout formed in the conductive layer(s) of the carrier substrate 2. It is to be understood that only the conductive layer(s) of the carrier substrate 2 are depicted in most of the appended figures, and that the insulating layer(s) of the carrier substrate 2 is/are not depicted in most figures in order to more clearly illustrate the arrangement of the first and second slots in the carrier substrate 2. For example with reference to Figures 1 to 7, the insulating layer(s) of the carrier substrate 2 (which thus is/are not shown in those figures) may overlie the depicted upper side of the conductive layer of the carrier substrate 2. However, Figure 8, which will be further described in the following, depicts the conductive layer(s) of the carrier substrate 2 as well as the insulating layer(s) of the carrier substrate 2. It is to be understood that each or any of the slots in the illustrated embodiments of present invention could be arranged in one or more conductive layers of the carrier substrate 2 and possibly in at least one insulating layer of the carrier substrate 2. Particularly in a case wherein one or more (or each) of the first slots and the second slots comprises a slot in the carrier substrate 2 - formed in at least one conductive layer of the carrier substrate 2 and in at least one insulating layer of the carrier substrate 2 - that or those slots may be metallized to increase capacitance between opposite edges of the slot(s).

[0063] The carrier substrate 2 comprises a first portion

11 and at least one second portion 12, 13, wherein each of the at least one second portion 12, 13 includes a part or portion of the boundary 14 of the carrier substrate 2. The first portion 11 of the carrier substrate 2 and each second portion 12, 13 of the carrier substrate 2 are adjoining each other. The first portion 11 of the carrier substrate 2 and each second portion 12, 13 of the carrier substrate 2 are arranged in relation to each other such that for each second portion 12, 13 of the carrier substrate 2, the second portion 12, 13 of the carrier substrate 2 forms an angle relative to the first portion 11 of the carrier substrate 2.

[0064] With reference to Figure 1 as well as Figures 2 to 7, the insulating layer(s) of the carrier substrate 2 (which are not shown in the figures) may overlie the depicted conductive layer(s) of the carrier substrate 2 on both the first portion 11 of the carrier substrate 2 and each or any second portion 12, 13 of the carrier substrate 2. Since the first portion 11 of the carrier substrate 2 and each second portion 12, 13 of the carrier substrate 2 are arranged in relation to each other such that for each second portion 12, 13 of the carrier substrate 2, the second portion 12, 13 of the carrier substrate 2 forms an angle relative to the first portion 11 of the carrier substrate 2, the insulating layer(s) of the carrier substrate 2 may not be planar.

[0065] In accordance with the embodiment of the present invention illustrated in Figure 1, the carrier substrate 2 comprises four second portions, two of which are indicated by reference numerals 12 and 13, one of which is partly visible at the left-hand side in Figure 1 but not indicated by any reference numeral, and one of which is not visible in Figure 1 (it is at the second slot 9). As illustrated in Figure 1, each of the second portions 12, 13 of the carrier substrate 2 has a triangular shape. However, it is to be understood that the second portions 12, 13 of the carrier substrate 2 may have another or other shapes, e.g. square or rectangular shapes.

[0066] In accordance with the embodiment of the present invention illustrated in Figure 1, each second slot 7, 8, 9, 10 of the at least one pair of second slots 7, 8, 9, 10 may extend on or in one of the at least one second portion 12, 13 of the carrier substrate 2. According to the embodiment of the present invention illustrated in Figure 1, each of the second slots 7, 8, 9, 10 extends on or in a respective one of the four second portions of the carrier substrate 2.

[0067] Further in accordance with the embodiment of the present invention illustrated in Figure 1, the arrangement of the first slots 3, 4, 5, 6 of the pairs of first slots 3, 4, 5, 6 and the second slots 7, 8, 9, 10 of the pairs of second slots 7, 8, 9, 10 in or on the carrier substrate, respectively, is mirror-symmetric (as illustrated in Figure 1) with respect to each of two mutually perpendicular planes through a center point of the carrier substrate 2 as seen from above the carrier substrate 2. In Figure 1, the center point may be defined by the point on the carrier substrate 2 where the first slots 3, 4, 5, 6 would meet if they all would be extended towards the center of the carrier substrate 2.

[0068] The arrangement of the second parts 12, 13 of the carrier substrate 2 may be mirror-symmetric, e.g., with respect to the above-mentioned symmetry planes, such as illustrated in Figure 1.

[0069] It is to be understood that the antenna element 1 could comprise more than two pairs of first slots and more than two pairs of second slots. The number of pairs of first slots and the number of pairs of second slots may be the same. Irrespective of the number of pairs of first slots and the number of pairs of second slots, the arrangement of the first slots of the pairs of first slots and the second slots of the pairs of second slots in or on the carrier substrate, respectively, is mirror-symmetric with respect to each of two mutually perpendicular planes through a center point of the carrier substrate 2 as seen from above the carrier substrate 2.

[0070] As indicated in Figure 1, the first portion 11 of the carrier substrate 2 and each second portion 12, 13 of the carrier substrate 2 may for example be formed from at least one folded or bent portion of the carrier substrate 2. The folded or bent portion of the carrier substrate 2 may be arranged so that for each second portion 12, 13 of the carrier substrate 2, the second portion 12, 13 of the carrier substrate 2 forms an angle relative to the first portion 11 of the carrier substrate 2. In accordance with the embodiment of the present invention illustrated in Figure 1, the folded or bent portion of the carrier substrate 2 may be arranged so that for each second portion 12, 13 of the carrier substrate 2, the second portion 12, 13 of the carrier substrate 2 forms an angle of 90 degrees, or substantially 90 degrees, to the first portion 11 of the carrier substrate 2 (cf. Figure 9). However, angles other than 90 degrees are contemplated and may be employed in different embodiments of the present invention (cf. Figure 10).

[0071] In accordance with the embodiment of the present invention illustrated in Figure 1, the first portion 11 of the carrier substrate 2 and each of the second portions 12, 13 of the carrier substrate 2 are planar (or substantially planar). However, it is to be understood that it is not required that the first portion 11 of the carrier substrate 2 and each of the second portions 12, 13 of the carrier substrate 2 are planar, and that the first portion 11 and/or any of the second portions 12, 13 may be non-planar, at least in part.

[0072] As mentioned in the foregoing, each first slot 3, 4, 5, 6 of the at least one pair (e.g., two pairs) of first slots 3, 4, 5, 6 has at least one associated feed point (not illustrated in Figure 1). The feed points may be connected to a feed network of the antenna element 1. The feed network may be configured to transport RF signals to the feed points. The feed network may include all components necessary to feed the antenna element with RF signals having appropriate amplitude and phase values. The feed network may for example include one or more coaxial lines, microstrip lines and/or other types of transmission lines. A person skilled in the art will recognize that the feed network may be implemented or realized in different ways and detailed description of the feed network herein is therefore omitted. The feed network is not depicted in Figure 1. Two examples of how (parts of) the feed network may be implemented or realized in an antenna element such as the antenna element illustrated in Figure 1 are depicted in Figures 21 and 22, respectively.

[0073] In accordance with the embodiment of the present invention illustrated in Figure 1, the feed network may comprise, or be connected to, two transmission lines 21, 22 such as coaxial lines. Possibly, the transmission lines 21, 22 may be comprised in the antenna element 1. The transmission lines 21, 22 may be configured (e.g., arranged so that they have a sufficiently high rigidity) such that they are capable of supporting the carrier substrate 2, for example at a selected distance above an at least in part conductive reflector (not shown in Figure 1; cf. Figures 19 and 20). The transmission lines 21, 22 may at least in part form a structure that may be arranged to support the carrier substrate 2, for example at a selected distance above an at least in part conductive reflector.

[0074] It is to be understood that the number of transmission lines illustrated in Figure 1 is exemplifying, and that there could be fewer or more transmission lines that may be comprised in the antenna element 1 or the feed network or that may be connected to the feed network. In accordance with the embodiment of the present invention illustrated in Figure 1, there are two pairs of first slots 3, 4, 5, 6, wherein each of the first slots 3, 4, 5, 6 has at least one associated feed point (not shown in Figure 1) arranged to be fed with RF signals such that RF waves are excited from the first slot 3, 4, 5, 6. Thus, in the illustrated embodiment, there are four first slots 3, 4, 5, 6 arranged in or on the carrier substrate 2, and two transmission lines 21, 22. Each of the two transmission lines 21, 22 may transport RF signals to the respective feed point(s) associated with two of the first slot 3, 4, 5, 6 such that each of the transmission lines 21, 22 feeds two of the four first slots 3, 4, 5, 6. In such a case, the RF signals that are conveyed in each of the two transmission lines 21, 22 will generally have to be split for subsequent transport to the respective ones of the two first slots 3, 4, 5, 6 of the four first slots 3, 4, 5, 6. Possibly, each of the first slots 3, 4, 5, 6 may be fed by a separate transmission line. For example in case there are four first slots 3, 4, 5, 6, such as in the illustrated embodiment, there may be at least four transmission lines, and not only two as illustrated in Figure 1, where each of the transmission lines may transport RF signals to the respective feed point(s) associated with a respective one of the first slot 3, 4, 5, 6. Thus, there may possibly be as many transmission lines as there is first slots, and each of the transmission lines may feed a respective one of the first slots. This applies to any of the embodiments of the present invention disclosed herein.

[0075] Figure 2 is a schematic perspective view of an antenna element 1 according to one or more embodiments of the present invention. The antenna element 1 illustrated in Figure 2 is similar to the antenna element 1 illustrated in Figure 1, and the same reference numerals in Figures 1 and 2 denote the same or similar components, having the same or similar functions. The carrier substrate 2 of the antenna element 1 illustrated in Figure 2 comprises at least one conductive layer and at least one insulating layer. It is to be understood that only the conductive layer(s) of the carrier substrate 2 are depicted in Figure 2, and that the insulating layer(s) of the carrier substrate 2 is/are not depicted in Figure 2 in order to more clearly illustrate the arrangement of the first and second slots in the carrier substrate 2. Compared to the antenna element 1 illustrated in Figure 1, in the antenna element 1 illustrated in Figure 2, the second portions 12, 13 of the carrier substrate 2 have a rectangular shape. As in the embodiment of the present invention illustrated in Figure 1, the arrangement of the second parts 12, 13 of the carrier substrate 2 are mirror-symmetric with respect to the above-mentioned symmetry planes as described in the foregoing with reference to Figure 1.

[0076] Just as the antenna element 1 illustrated in Figure 1, the antenna element 1 illustrated in Figure 2 may comprise a feed network. Each feed point that may be associated with each first slot 3, 4, 5, 6 of the at least one pair (e.g., two pairs) of first slots 3, 4, 5, 6 may be connected to the feed network. The feed network is not depicted in Figure 2. Two examples of how the feed network may be implemented or realized in an antenna element such as the antenna element illustrated in Figure 2 are depicted in Figures 21 and 22.

[0077] In accordance with the embodiment of the present invention illustrated in Figure 2, the feed network may comprise, or be connected to, four transmission lines 21, 22 such as coaxial lines (only two of the transmission lines are indicated by reference numerals in Figure 2). Each of the transmission lines 21, 22 may transport RF signals to the respective feed point(s) associated with a respective one of the first slot 3, 4, 5, 6.

[0078] Figure 3 is a schematic perspective view of an antenna element 1 according to one or more embodiments of the present invention. The antenna element 1 illustrated in Figure 3 is similar to the antenna element 1 illustrated in Figure 1 or 2, and the same reference numerals in Figure 1 or 2 and Figure 3 denote the same or similar components, having the same or similar functions. Figure 4 is a schematic view from above of the antenna element 1 illustrated in Figure 3. The carrier substrate 2 of the antenna element 1 illustrated in Figures 3 and 4 comprises at least one conductive layer and at least one insulating layer. Compared to the antenna element 1 illustrated in Figure 1 or 2, the antenna element 1 illustrated in Figures 3 and 4 comprises two pairs of cavities 15, 16, 17, 18, e.g., cavities 16 and 18 and cavities 15 and 17, in at least a conductive layer (possibly in more than one conductive layer) of the carrier substrate 2. Each pair of cavities 15, 16, 17, 18 (e.g., cavities 16 and 18 and cavities 15 and 17) is associated with a pair of second slots 7, 8, 9, 10 (e.g., the second slots 8 and 9 and the second slots 7 and 10). Each slot of the pair of second slots 7, 8, 9, 10 extends from a boundary of one of the pair of cavities 15, 16, 17, 18 in the carrier substrate 2 to the boundary 14 of the carrier substrate 2.

[0079] It is to be understood that only the conductive layer(s) of the carrier substrate 2 are depicted in Figures 3 and 4, and that the insulating layer(s) of the carrier substrate 2 is/are not depicted in Figures 3 and 4 in order to more clearly illustrate the arrangement of the first and second slots in the carrier substrate 2 and the cavities 15, 16, 17, 18.

[0080] It is to be understood that the antenna element 1 may comprise fewer or more than two pairs of cavities. Further, in alternative or in addition, at least one pair of cavities might be associated with a pair of first slots 3, 4, 5, 6 (e.g., the first slots 3 and 6, or the first slots 4 and 5). Each slot of the pair of first slots 3, 4, 5, 6 could extend from a boundary of one of the pair of cavities or recesses in the carrier substrate to the boundary 14 of the carrier substrate 2 (this case is not shown in Figures 3 and 4). Thus, in general, the antenna element 1 may comprise at least one pair of cavities in at least a conductive layer of the carrier substrate 2, where each pair of cavities may be associated with a pair of first slots or a pair of second slots. Each slot of the pair of first slots or the pair of second slots may extend from a boundary of one of the pair of cavities in the carrier substrate to the boundary 14 of the carrier substrate 2.

[0081] The arrangement of the cavities or recesses of the pairs of cavities or recesses may be symmetric, e.g., with respect to above-mentioned symmetry planes as described in the foregoing with reference to Figure 1. Thus, the arrangement of the cavities or recesses of the pairs of cavities or recesses may be symmetric with respect to each of two mutually perpendicular symmetry planes through a center point of the carrier substrate 2, as seen from above the carrier substrate 2. For example, and in accordance with the embodiment of the present invention illustrated in Figures 3 and 4, the arrangement of the cavities 15, 16, 17, 18 of the pairs of cavities 15, 16, 17, 18, e.g., cavities 16 and 18 and cavities 15 and 17, are symmetric with respect to above-mentioned symmetry planes as described in the foregoing with reference to Figure 1.

[0082] In accordance with the embodiment of the present invention illustrated in Figures 3 and 4, each cavity 15, 16, 17, 18 has a square shape as seen from above the cavity 15, 16, 17, 18. However, another shape of each or any cavity 15, 16, 17, 18 is possible, e.g., a circular, rectangular, rhombic, rhomboidal, or parallelogrammatic shape. In order to achieve two orthogonal polarizations in the far field region of antenna element 1, the shape of each or any of the cavities 15, 16, 17, 18 should be such that the arrangement of the cavities of the pairs of cavities is symmetric with respect to each of two mutually perpendicular symmetry planes through a center point of the carrier substrate 2, as seen from above the carrier substrate 2.

[0083] It is to be understood that although the cavities 15, 16, 17, 18 depicted in Figures 3 and 4 are located in the first portion 11 of the carrier substrate 2, each or any of the cavities 15, 16, 17, 18 could at least in part be located in one of the second portions 12, 13 of the carrier substrate 2. The arrangement/configuration of each or any of the cavities 15, 16, 17, 18 should however preferably be such that the arrangement of the cavities of the pairs of cavities is symmetric with respect to each of two mutually perpendicular symmetry planes through a center point of the carrier substrate 2, as seen from above the carrier substrate 2, in order to achieve two orthogonal polarizations in the far field region of antenna element 1.

[0084] Figure 5 is a schematic perspective view of an antenna element 1 according to one or more embodiments of the present invention. The antenna element 1 illustrated in Figure 5 is similar to the antenna element 1 illustrated in Figure 3, and the same reference numerals in Figures 3 and 5 denote the same or similar components, having the same or similar functions.

[0085] Compared to the antenna element 1 illustrated in Figure 3, the carrier substrate 2 of the antenna element 1 illustrated in Figure 5 comprises third portions 23, 24, wherein each of the third portions 23, 24 includes a part or portion of the boundary 14 of the carrier substrate 2. The first portion 11 of the carrier substrate 2 and each third portion 23, 24 of the carrier substrate 2 are adjoining each other. The first portion 11 of the carrier substrate 2 and each third portion 12, 13 of the carrier substrate 2 are arranged in relation to each other such that for each third portion 23, 24, the third portion 23, 24 of the carrier substrate 2 forms an angle relative to the first portion 11 of the carrier substrate 2. Each first slot 3, 4, 5, 6 of the at least one pair of first slots 3, 4, 5, 6 extends on or in one of the third portions 23, 24 of the carrier substrate 2.

[0086] In accordance with the embodiment of the present invention illustrated in Figure 5, the carrier substrate 2 comprises four third portions, two of which are indicated by reference numerals 23 and 24, and two of which are partly visible but not indicated by any reference numerals in Figure 5 (at the first slots 3 and 5, respectively). As illustrated in Figure 5, each of the third portions 23, 24 of the carrier substrate 2 may have a rectangular shape. However, it is to be understood that the third portions 23, 24 of the carrier substrate 2 may have another or other shapes, e.g. square or triangular shapes.

[0087] By way of the third portions 23, 24 of the carrier substrate 2, it may be facilitated to increase the length of the first slots 3, 4, 5, 6, if desired or required to increase the length thereof.

[0088] As in the embodiments of the present invention illustrated in Figures 1 to 3, the arrangement of the second parts 12, 13 of the carrier substrate 2 are symmetric, e.g., with respect to above-mentioned symmetry planes as described in the foregoing with reference to Figure 1. It is to be understood that while the second portions 12, 13 of the carrier substrate 2 have a triangular shape in Figure 5, the second portions 12, 13 of the carrier substrate 2 may have another or other shapes, e.g. square shapes. In accordance with the embodiment of the present invention illustrated in Figure 5, the arrangement of the third parts 23, 24 of the carrier substrate 2 is also symmetric, e.g., with respect to above-mentioned symmetry planes as described in the foregoing with reference to Figure 1.

[0089] It is to be understood that the cavities 15, 16, 17, 18 may be omitted in the antenna element 1 illustrated in Figure 5 (e.g., such as in the antenna element 1 illustrated in Figure 1).

[0090] Figure 6 is a schematic perspective view of an antenna element 1 according to one or more embodiments of the present invention. The antenna element 1 illustrated in Figure 6 is similar to the antenna element 1 illustrated in Figure 1 and has the same or similar components, having the same or similar function, and reference numerals for the carrier substrate 2 and related components are omitted in Figure 6. Compared to the antenna element 1 illustrated in Figure 1, the antenna element 1 illustrated in Figure 6 comprises a parasitic patch 20 arranged at a distance from the carrier substrate 2.

[0091] Figure 7 is a schematic perspective view of an antenna element 1 according to one or more embodiments of the present invention. The antenna element 1 illustrated in Figure 7 is similar to the antenna element 1 illustrated in Figure 3 and has the same or similar components, having the same or similar function, and reference numerals for the carrier substrate 2 and related components are omitted in Figure 7. Compared to the antenna element 1 illustrated in Figure 3, the antenna element 1 illustrated in Figure 7 comprises a parasitic patch 20 arranged at a distance from the carrier substrate 2.

[0092] With reference to Figure 6 and/or Figure 7, the parasitic patch 20 may for example be arranged at a distance from the carrier substrate by means of one or more dielectric supports or the like (not shown in Figures 6 and 7). The one or more dielectric supports or the like may be arranged intermediate the carrier substrate and the parasitic patch 20.

[0093] In accordance with the embodiments of the present invention illustrated in Figures 6 and 7, the parasitic patch 20 is planar (or substantially planar), is constituted by a solid body (having no hole(s) therein), and has a square shape as seen from above the parasitic patch 20. However, with reference to Figure 6 and/or Figure 7, it is to be understood that the parasitic patch 20 may possibly be non-solid (e.g., having one or more holes, slots, etc.), be non-planar, and/or may have a shape that as seen from above the parasitic patch 20 is different from a square (but instead for example circular); cf. Figures 12 to 15. Also, with further reference to Figure 6 and/or Figure 7, the antenna element 1 may comprise more than one parasitic patch. In case the antenna element 1 would comprise several parasitic patches, the parasitic patches may for example be arranged (e.g., stacked) one above the other, with a selected distance between different parasitic patches, and/or the parasitic patches may be arranged side by side.

[0094] Figure 8 is a schematic perspective view of an antenna element 1 according to one or more embodiments of the present invention. The antenna element 1 illustrated in Figure 8 is similar to the antenna element 1 illustrated in Figure 1, and the same reference numerals in Figures 1 and 8 denote the same or similar components, having the same or similar function. As described in the foregoing, only the conductive layer(s) of the carrier substrate 2 is/are depicted in, e.g., Figure 1, while the insulating layer(s) of the carrier substrate 2 is/are not shown in order to more clearly illustrate the arrangement of the first and second slots in the carrier substrate 2. Figure 8 illustrates also the insulating layer(s) of the carrier substrate 2, which insulating layer(s) is/are overlying one side of the conductive layer(s) of the carrier substrate 2.

[0095] Figures 9 and 10 are schematic side views of an antenna element according to one or more embodiments of the present invention, each of which may be configured in the same way or similarly to the antenna element 1 illustrated in for example Figure 1 or Figure 2. The same reference numerals in Figures 9 and 10 and in Figure 1 or Figure 2 denote the same or similar components, having the same or similar function. As described in the foregoing, for example with reference to Figure 1, the first portion 11 of the carrier substrate 2 and each second portion 12, 13 of the carrier substrate 2 are arranged in relation to each other such that for each second portion 12, 13 of the carrier substrate 2, the second portion 12, 13 of the carrier substrate 2 forms an angle relative to the first portion 11 of the carrier substrate 2. To that end, the first portion 11 of the carrier substrate 2 and each second portion 12, 13 of the carrier substrate 2 may for example be formed from at least one folded or bent portion of the carrier substrate 2. The folded or bent portion of the carrier substrate 2 may be arranged so that for each second portion 12, 13 of the carrier substrate 2, the second portion 12, 13 of the carrier substrate 2 forms an angle relative to the first portion 11 of the carrier substrate 2. For each second portion 12, 13 of the carrier substrate 2, the second portion 12, 13 of the carrier substrate 2 may for example form an angle of 90 degrees, or substantially 90 degrees, relative to the first portion 11 of the carrier substrate 2. Such a case is illustrated in Figure 9. However, angles other than 90 degrees are contemplated and may be employed in different embodiments of the present invention. Such a case is illustrated in Figure 10, where for each second portion 12, 13 of the carrier substrate 2, the second portion 12, 13 of the carrier substrate 2 forms an angle α, where $\alpha \neq 90$ degrees, relative to the first portion 11 of the carrier substrate 2.

[0096] Figure 11 is a schematic side view of an antenna element according to one or more embodiments of the present invention. The antenna element illustrated in Figure 11 is similar to the antenna element illustrated in Figure 9, and the same reference numerals in Figure 11 and in Figure 9 denote the same or similar components, having the same or similar function. Compared to the antenna element illustrated in Figure 9, in the antenna element illustrated in Figure 11, the second portion 12 comprises two different portions 12a, 12b, and the second portion 13 comprises two different portions 13a, 13b. The portions 12a, 12b of the second portion 12 are adjoining each other and arranged at an angle with respect to each other. The angle at which the portions 12a, 12b of the second portion 12 are arranged in relation to each other may for example be 90 degrees, or substantially 90 degrees, as illustrated in Figure 11, but angles different from 90 degrees are possible. Similarly, the portions 13a, 13b of the second portion 13 are adjoining each other and arranged at an angle with respect to each other. The angle at which the portions 13a, 13b of the second portion 13 are arranged in relation to each other may for example be 90 degrees, or substantially 90 degrees, as illustrated in Figure 11, but angles different from 90 degrees are possible.

[0097] Possibly, each or any of the second portion 12 and the second portion 13 could comprise more than two different portions, wherein each of the different portions may be arranged at an angle with respect to at least one other of the different portions. Generally, each or any of the second portion 12 and the second portion 13 may comprise at least two different portions, wherein at least two of the different portions are adjoining each other and arranged at an angle with respect to each other.

[0098] Figures 12 to 15 are schematic views from the above of a parasitic patch 20 in accordance with one or more embodiments of the present invention, illustrating different possible shapes of the parasitic patch 20 as seen from above the parasitic patch 20. As illustrated in Figure 12, and in accordance with the embodiments of the present invention illustrated in Figures 6 and 7, the parasitic patch 20 may have a square (or substantially square) shape as seen from above. As illustrated in Figure 14, the parasitic patch 20 may have a circular (or substantially circular) shape as seen from above. The parasitic patch may have one or more openings, or through-holes. Two examples are illustrated in Figures 13 and 15, which illustrate that the parasitic patch 20 may have a shape as seen from above as a square frame or a circular ring, respectively, and hence that the parasitic patch 20 may have a central opening.

[0099] Figures 16 to 18 are schematic views from above of a portion of a carrier substrate of an antenna element in accordance with one or more embodiments of the present invention, illustrating different possible shapes of a cavity 15 as described in the foregoing. Other shapes than the ones illustrated in Figures 16 to 18 are however possible. Even though the cavity is referenced by the reference numeral 15 in Figures 16 to 18, it is to be understood that any of the cavities 15, 16, 17, 18 described in the foregoing may have a shape as illustrated in any of Figures 16 to 18.

[0100] As illustrated in Figures 16 and 17, and in accordance with the embodiments of the present invention shown in Figures 3 to 5 and 7, the cavity 15 may have a square (or substantially square) shape as seen from above. In accordance with the embodiment of the present invention illustrated in Figure 16, a second slot 7 may be extending from a boundary of the cavity 15 in the carrier substrate 2.

[0101] As illustrated in Figure 18, the cavity 15 may have a circular (or substantially circular) shape as seen from above. In accordance with the embodiment of the present invention illustrated in Figure 18, a second slot 7 may be extending from a boundary of the cavity 15 in the carrier substrate 2.

[0102] As described in the foregoing with reference to Figure 3, in alternative or in addition, a first slot could be extending from a boundary of a cavity in the carrier substrate. A cavity associated with a first slot could for example have a shape as illustrated in any of Figures 16 to 18.

[0103] Figure 19 is a schematic perspective view of an antenna 30 according to an embodiment of the present invention. The antenna 30 comprises a plurality of antenna elements 1 according to embodiments of the present invention and an at least in part conductive reflector 31. According to the embodiment of the present invention illustrated in Figure 19, each of the antenna elements 1 is configured in accordance with the antenna element 1 described with reference to Figure 1. It is however to be understood that each or any of the antenna elements 1 could be configured in accordance with another or other embodiments of the present invention. While Figure 19 illustrates four antenna elements, it is to be understood that the antenna 30 may comprise more or fewer than four antenna elements. Each of the antenna elements 1 - which in the context of the embodiment of the present invention illustrated in Figure 19 should be understood as including the carrier substrate 2 but not including the transmission lines 21, 22 - is arranged at a distance from the reflector 31 and at a distance from the other antenna elements 1.

[0104] In accordance with the embodiment of the present invention illustrated in Figure 19, the antenna elements 1 are arranged in a succession, and the antenna elements 1 are further arranged in an array. In accordance with the embodiment of the present invention illustrated in Figure 19, the antenna elements 1 are arranged in a succession along the x-axis of the coordinate system (*x,y,z*) indicated in Figure 19. The array of antenna elements must not necessarily be linear, such as illustrated in Figure 19.

[0105] The reflector 31 may define an acting ground plane for the antenna elements 1. As illustrated in Figure 19, the reflector 31 may be plate-shaped, but this is not required and other shapes of the reflector 31 are possible. The reflector 31 may serve as a reflecting structure for

RF waves radiated from each or any of the antenna elements 1.

[0106] Figure 20 is a perspective view of an antenna 30 according to another embodiment of the present invention. The same reference numerals in Figures 19 and 20 denote the same or similar components, having the same or similar functions. The antenna elements 1 of the antenna 30 illustrated in Figure 20 (only some of the antenna elements are indicated by a reference numeral in Figure 20) are also arranged in an array, but in a two-dimensional array instead of a linear array as in Figure 19, with successions of antenna elements 1 parallel to the x-axis and the y-axis of the coordinate system (*x,y,z*) indicated in Figure 20. While Figure 20 illustrates four times four antenna elements, it is to be understood that the antenna 30 may comprise more or fewer than four times four antenna elements. Generally, the array of antenna elements may comprise *n* times *m* antenna elements, where *n* and *m* are integer numbers.

[0107] It is to be understood that Figures 19 and 20 are both schematic. In particular, the proportion between the distance between the antenna elements 1 and the lateral extension of the antenna elements 1 (e.g., along the x-axis or γ-axis in the xy-plane, as defined by the coordinate system (x,y,z) indicated in Figures 19 and 20) in Figures 19 and 20 as well as the proportion between the lateral extension of the antenna elements 1 and the distance of the antenna elements 1 from the reflector 31 in Figures 19 and 20 are schematic only and for illustrating principles of one or more embodiments of the present invention. Further, the distances between the antenna elements 1 along the x-axis and/or y-axis in the xy-plane, as defined by the coordinate system (x,y,z) indicated in Figures 19 and 20, must not necessarily be the same (but they could be), and at least some of the distances may be different. Also, the antenna elements 1 in the antenna 30 illustrated in any of Figures 19 and 20 must not necessarily be the same with respect to frequency of RF waves radiated therefrom (but they could be).

[0108] With reference to any of the embodiments of the present invention illustrated in Figures 19 and 20, the reflector 31 may possibly be provided with one or more through-holes (not shown in Figures 19 and 20) through which the transmission lines 21, 22 of one or more of the antenna elements 1 may extend through. This may facilitate or allow for the transmission lines 21, 22 to be connected to (part of) a feed network for the antenna 30 that may be arranged beneath the reflector 31. The transmission lines 21, 22 may for example be constituted by or comprise coaxial transmission lines. In such a case, for one or more of the antenna elements 1, the outer conductors of the coaxial transmission lines may be connected to the reflector 31, e.g., by means of soldering, at the ends of the coaxial transmission lines which are closest to the reflector 31.

[0109] Each of Figures 21 and 22 is a schematic perspective view of an antenna element 1 according to one or more embodiments of the present invention. The antenna element 1 illustrated in Figures 21 and 22 is identical to the antenna element 1 illustrated in Figure 1. In Figures 21 and 22 two examples of how (part of) a feed network 40 of the antenna element 1 may be realized are depicted. Each feed point that may be associated with each first slot of the at least one pair (e.g., two pairs) of first slots may be connected to the feed network 40. As illustrated in Figures 21 and 22, the feed network (or part thereof) 40 crosses each first slot. In the antenna element 1 illustrated in Figure 21, the free ends of the parts of the feed network 40 that have crossed the first slots may be open-circuited. In the antenna element 1 illustrated in Figure 22, the free ends of the parts of the feed network 40 that have crossed the first slots may be short-circuited, e.g., by means of a metallized via connected to ground (not shown in Figure 22).

[0110] It is to be understood that the (parts of the) feed networks 40 illustrated in Figures 21 and 22 are exemplifying, and that the feed network may be realized in other ways. For example, while the (parts of the) feed networks 40 illustrated in Figures 21 and 22 employ microstrip technology, the feed network could in addition or in alternative employ stripline technology.

[0111] In conclusion, an antenna element is disclosed. The antenna element comprises an at least in part conductive carrier substrate. The antenna element comprises at least one pair of first slots arranged in or on the carrier substrate. Each first slot of the at least one pair of first slots has at least one associated feed point at the first slot, wherein the feed point is arranged to be fed with RF signals such that RF waves are excited from the first slot. The antenna element comprises at least one pair of second slots arranged in or on the carrier substrate. Each second slot of the at least one pair of second slots acts as a passive slot. Each slot of the at least one pair of first slots and the at least one pair of second slots extends from a point in or on the carrier substrate to a boundary of the carrier substrate. The carrier substrate comprises a first portion and at least one second portion. Each of the at least one second portion includes a part or portion of the carrier substrate's boundary. The first portion of the carrier substrate and each second portion of the carrier substrate are adjoining each other. The first portion of the carrier substrate and each second portion of the carrier substrate are arranged in relation to each other such that for each second portion of the carrier substrate, the second portion of the carrier substrate forms an angle relative to the first portion of the carrier substrate. Each second slot of the at least one pair of second slots may extend on or in one of the at least one second portion of the carrier substrate.

[0112] While the present invention has been illustrated in the appended drawings and the foregoing description, such illustration is to be considered illustrative or exemplifying and not restrictive; the present invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the appended claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. An antenna element (1) comprising:

an at least in part conductive carrier substrate (2);
at least one pair of first slots (3, 4, 5, 6) arranged in or on the carrier substrate, each first slot of the at least one pair of first slots having at least one associated feed point at the first slot, the feed point being arranged to be fed with radio frequency, RF, signals such that RF waves are excited from the first slot; and
at least one pair of second slots (7, 8, 9, 10) arranged in or on the carrier substrate, each second slot of the at least one pair of second slots acting as a passive slot;
each slot of the at least one pair of first slots and the at least one pair of second slots extending from a point in or on the carrier substrate to a boundary (14) of the carrier substrate;
wherein the carrier substrate comprises a first portion (11) and at least one second portion (12, 13), each of the at least one second portion including a part or portion of the carrier substrate's boundary, wherein the first portion of the carrier substrate and each second portion of the carrier substrate are adjoining each other, and wherein the first portion of the carrier substrate and each second portion of the carrier substrate are arranged in relation to each other such that for each second portion of the carrier substrate, the second portion of the carrier substrate forms an angle relative to the first portion of the carrier substrate, wherein each second slot of the at least one pair of second slots extends on or in one of the at least one second portion of the carrier substrate.

2. An antenna element according to claim 1, wherein each second slot of the at least one pair of second slots extends on or in one of the at least one second portion of the carrier substrate over to, and on or in, the first portion of the carrier substrate.

3. An antenna element according to claim 1, wherein each second slot of the at least one pair of second slots extends only on or in one of the at least one second portion of the carrier substrate, but not on or in the first portion of the carrier substrate.

4. An antenna element according to any one of claims 1-3, wherein each first slot of the at least one pair of first slots extends on or in the first portion of the carrier substrate.

5. An antenna element according to any one of claims 1-4, wherein each first slot of the at least one pair of first slots extends on or in one of the at least one second portion of the carrier substrate.

6. An antenna element according to any one of claims 1-5, wherein the antenna element comprises at least two pairs of first slots and at least two pairs of second slots, and wherein the arrangement of the first slots of the pairs of first slots and the second slots of the pairs of second slots in or on the carrier substrate, respectively, is symmetric with respect to each of two mutually perpendicular symmetry planes through a center point of the carrier substrate as seen from above the carrier substrate.

7. An antenna element according to any one of claims 1-6, wherein the carrier substrate comprises at least one conductive layer and at least one insulating layer, wherein each slot of the at least one pair of first slots and/or each slot of the at least one pair of second slots is formed in at least one conductive layer of the carrier substrate and in at least one insulating layer of the carrier substrate.

8. An antenna element according to claim 7, wherein each slot of the at least one pair of first slots and/or each slot of the at least one pair of second slots is metallized in order to increase capacitance between opposite edges of the slot.

9. An antenna element according to any one of claims 1-8, wherein the carrier substrate comprises at least one conductive layer and at least one insulating layer, and wherein the antenna element further comprises:
at least one pair of cavities or recesses (15, 16, 17, 18) in at least one conductive layer of the carrier substrate, each pair of cavities or recesses being associated with a pair of first slots or a pair of second slots, wherein each slot of the pair of first slots or the pair of second slots extends from a boundary of one of the pair of cavities or recesses in the carrier substrate to the boundary of the carrier substrate.

10. An antenna element according to claim 9, wherein the antenna element comprises at least two pairs of cavities or recesses, and wherein the arrangement of the cavities or recesses of the pairs of cavities or recesses is symmetric with respect to each of two mutually perpendicular symmetry planes through a center point of the carrier substrate, as seen from above the carrier substrate.

11. An antenna element according to any one of claims 1-10, wherein the feed points are connected to a feed network of the antenna element, the feed network being configured to transport RF signals to the feed points, wherein the antenna element further comprises at least one stub connected to the feed network.

12. An antenna element according to any one of claims 1-11, further comprising:
at least one at least in part conductive parasitic patch (20) arranged at a distance from the carrier substrate.

13. An antenna element according to any one of claims 1-12, wherein at least one of the at least one second portion (12, 13) of the carrier substrate comprises at least two different portions (12a, 12b; 13a, 13b), wherein at least two of the different portions are adjoining each other and are arranged to form an angle with respect to each other.

14. An antenna (30) comprising:

a plurality of antenna elements (1) according to any one of claims 1-13; and
at least one at least in part conductive reflector (31);
wherein at least the carrier substrate (2) of each of the antenna elements is arranged at a distance from the at least one reflector and at a distance from the other antenna element(s).

15. An antenna according to claim 14, wherein, for each antenna element of the plurality of antenna elements, the feed points at the first slots are arranged to be fed with radio frequency, RF, signals and excite the first slots such that the RF waves radiated from the antenna element have wavelengths within a selected wavelength range, wherein a center operating frequency of the selected wavelength range for one antenna element differs from a center operating frequency of the selected wavelength range for at least one of the other antenna element(s).

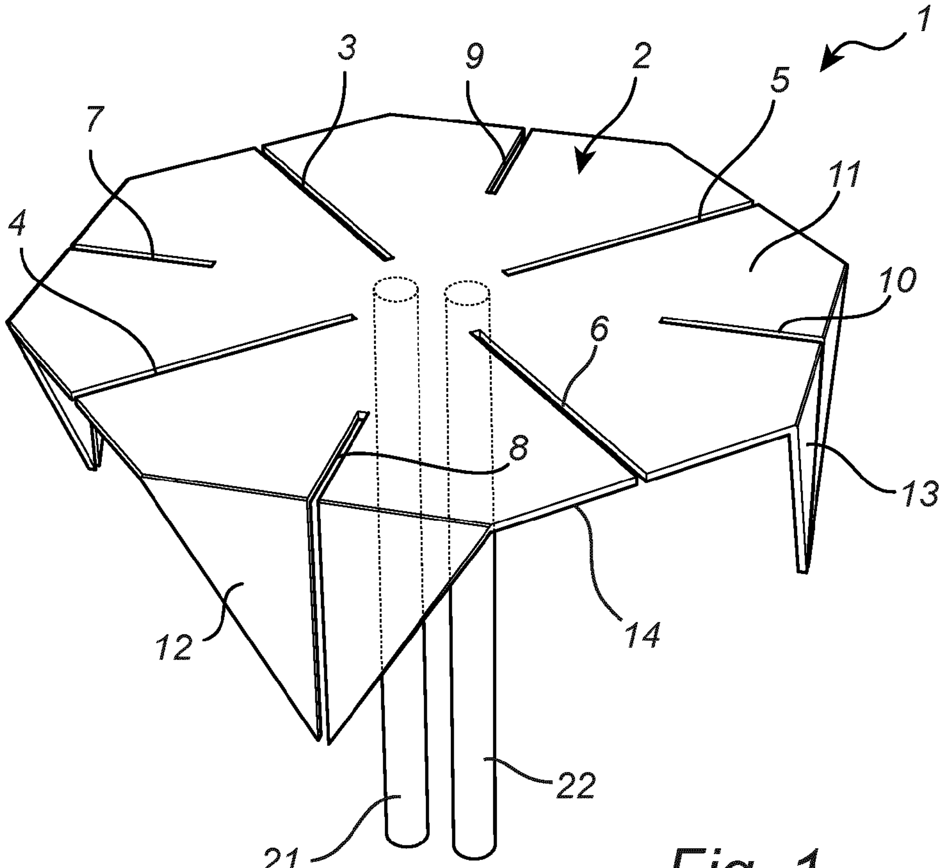

Fig. 1

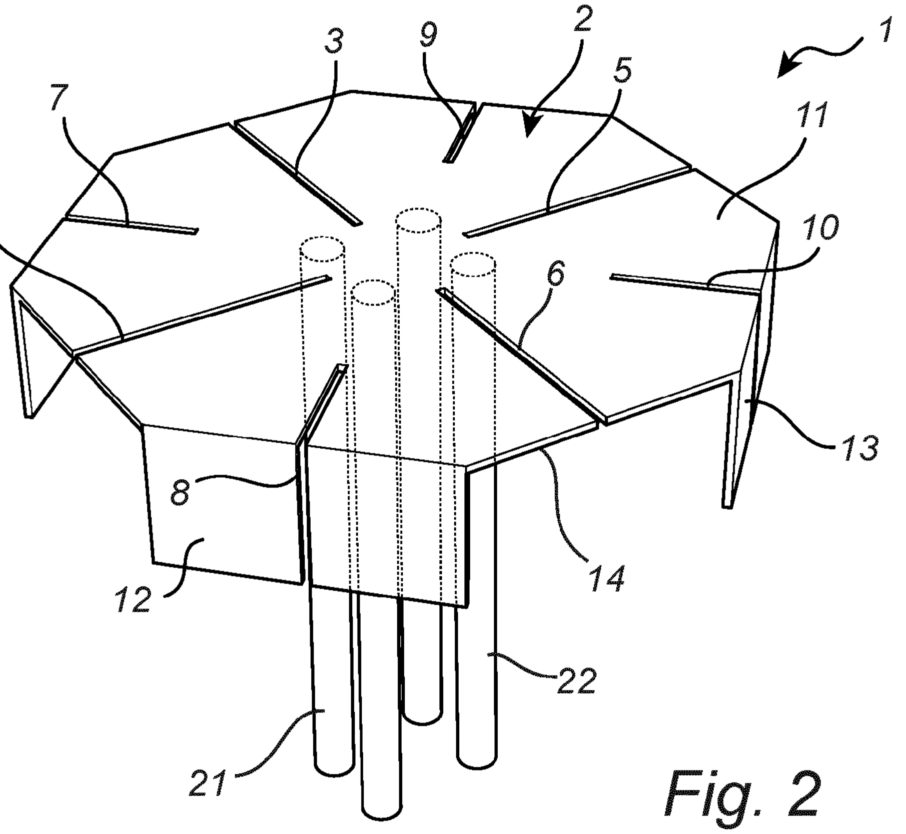

Fig. 2

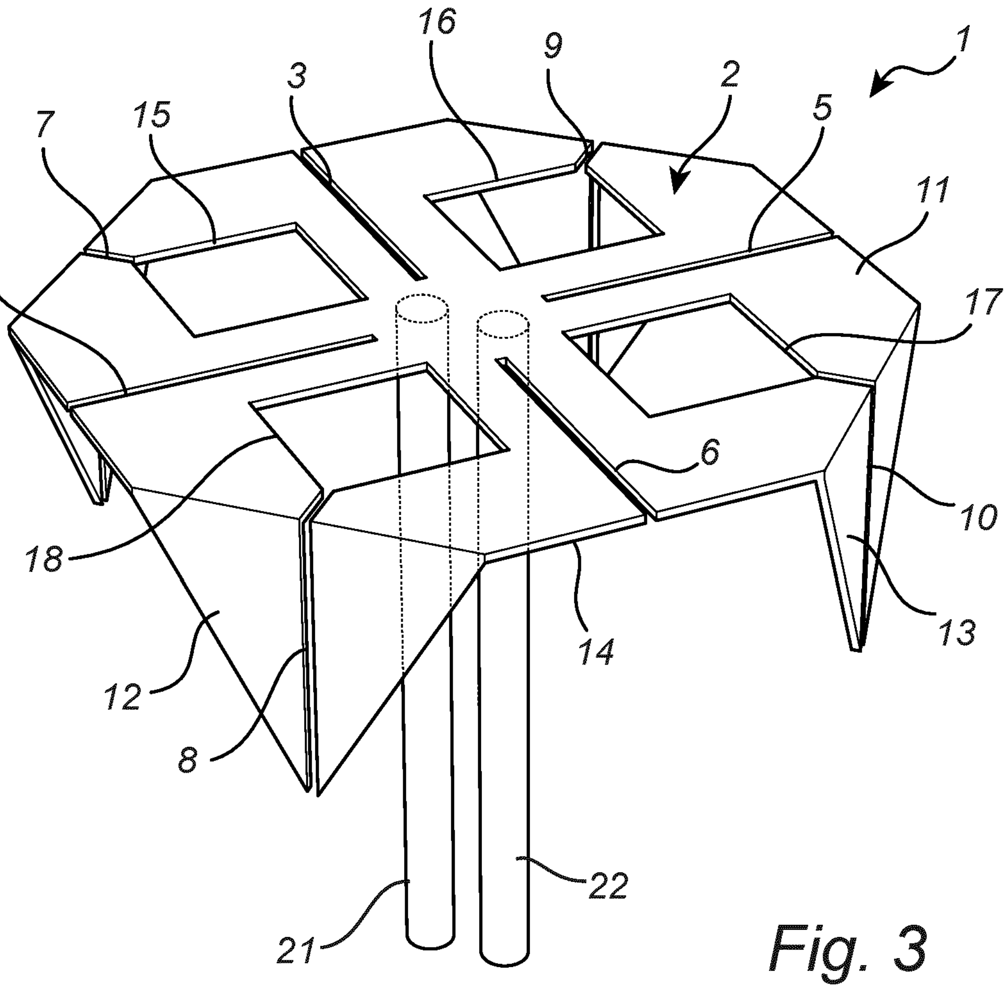
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Fig. 3

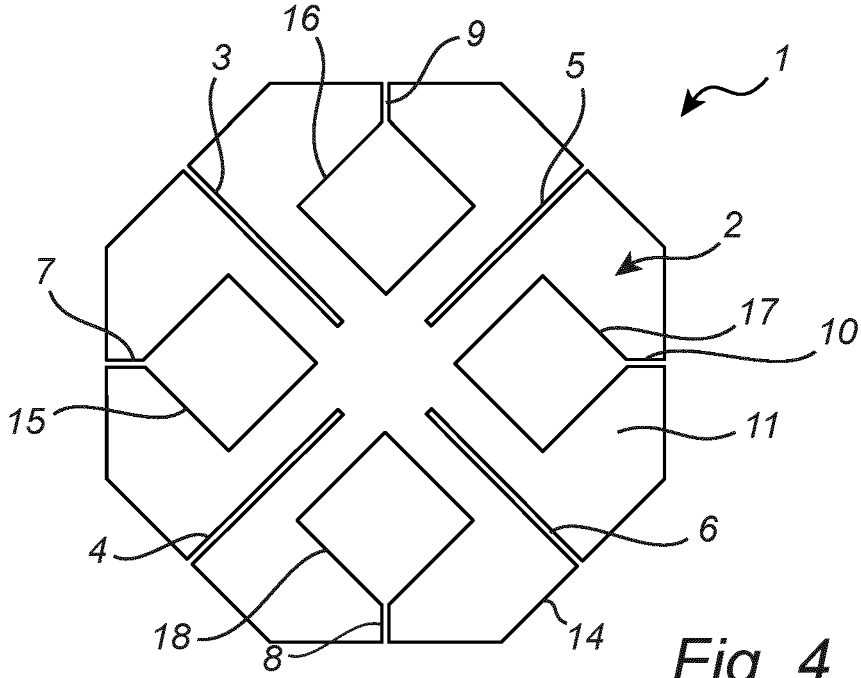
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Fig. 4

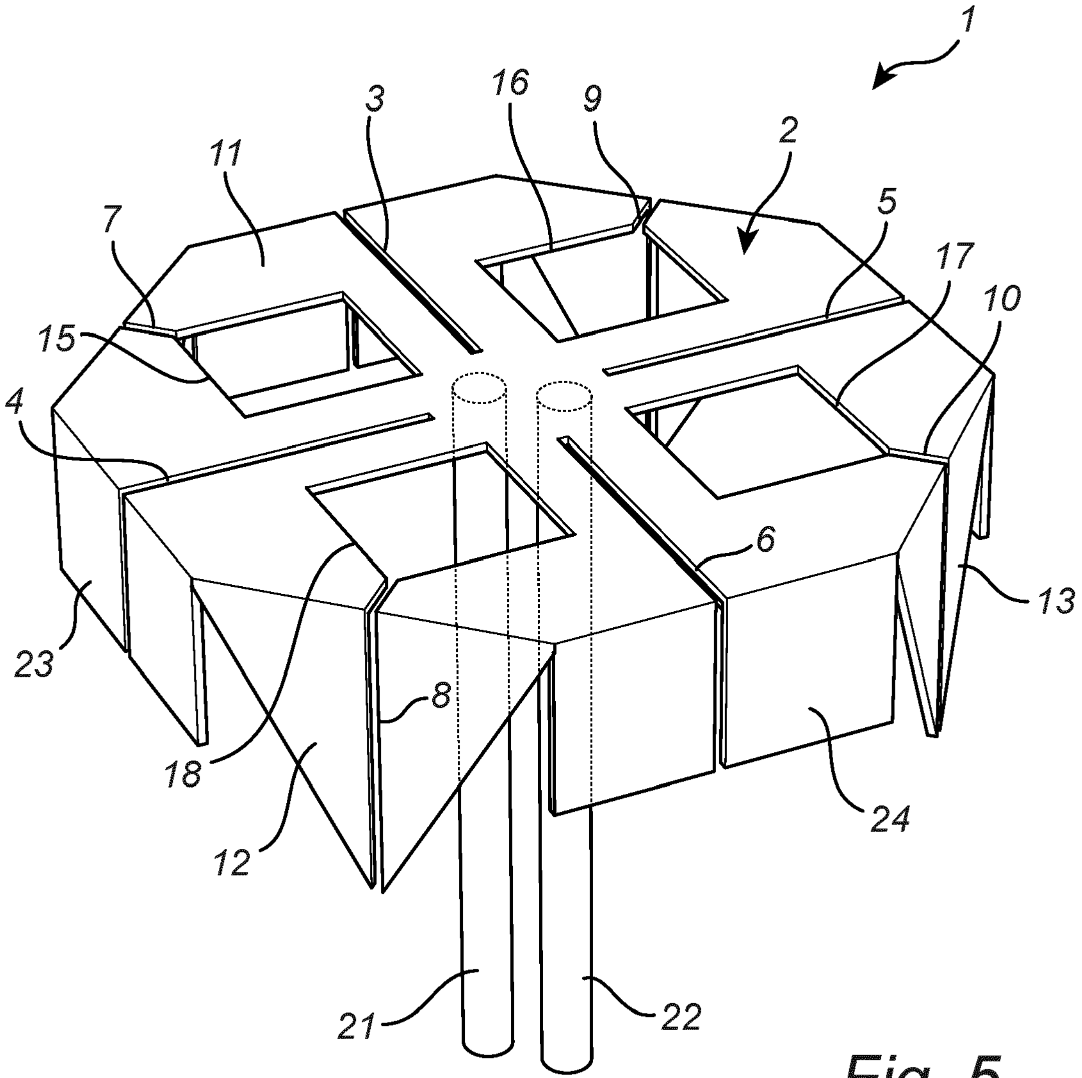

Fig. 5

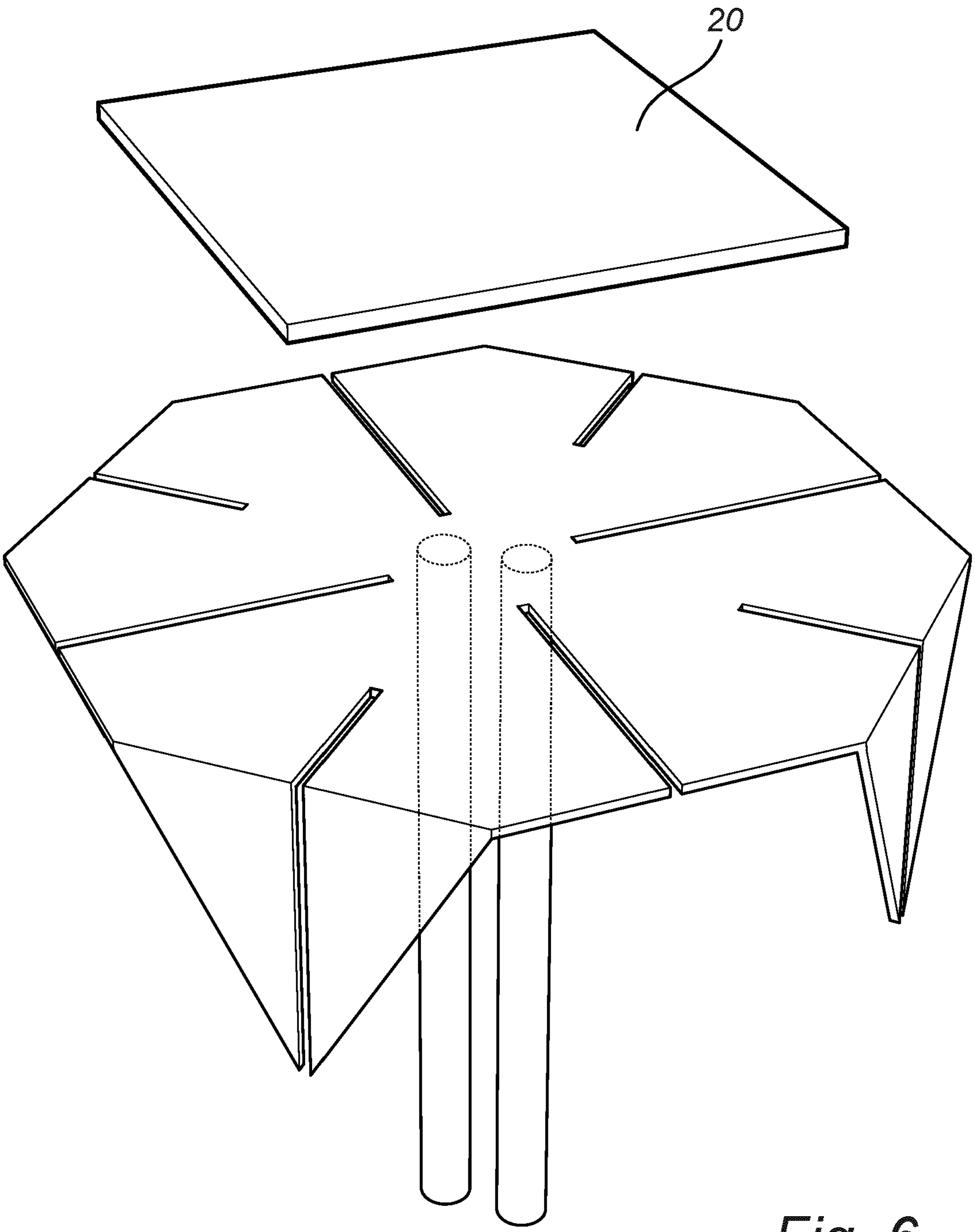

Fig. 6

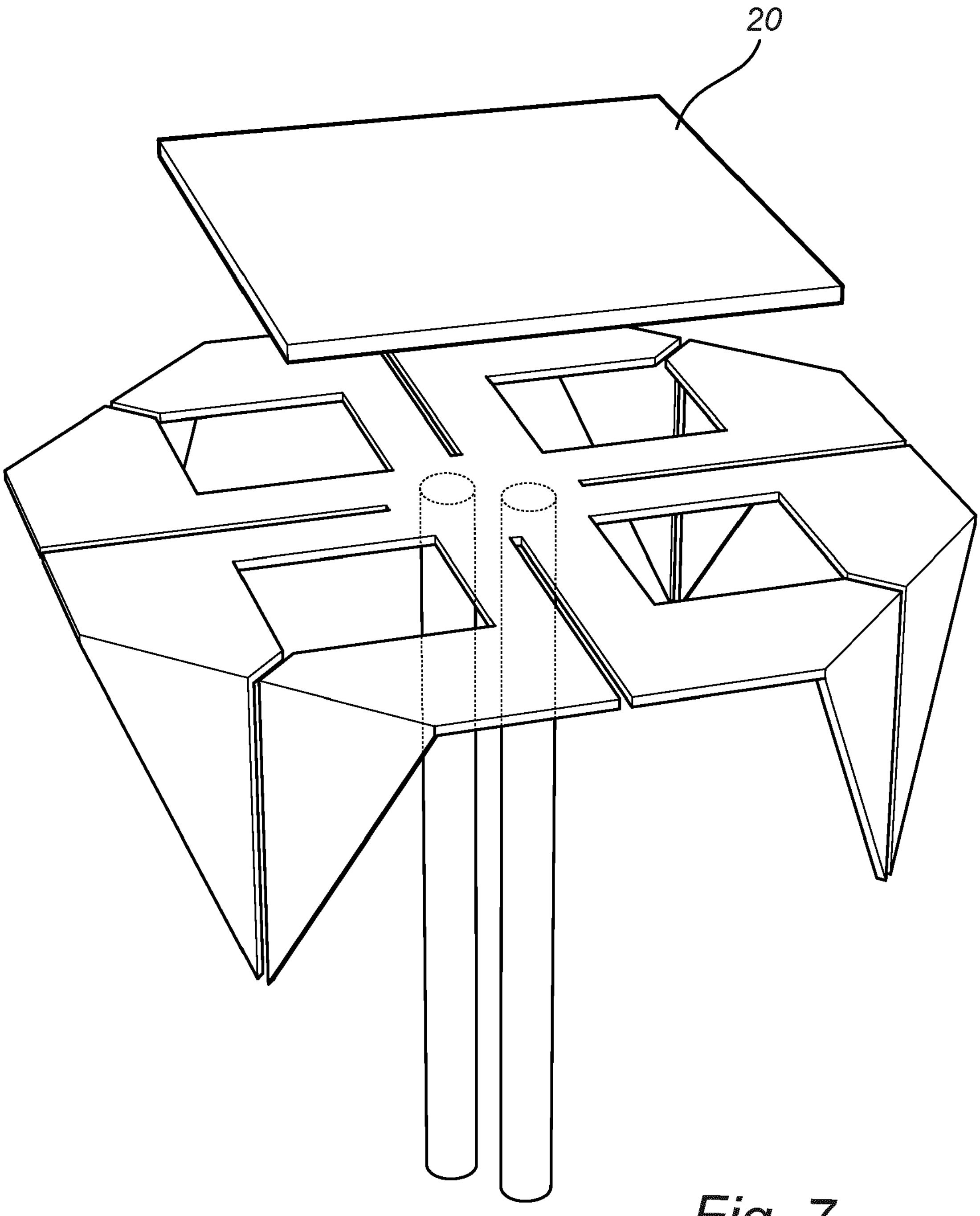

Fig. 7

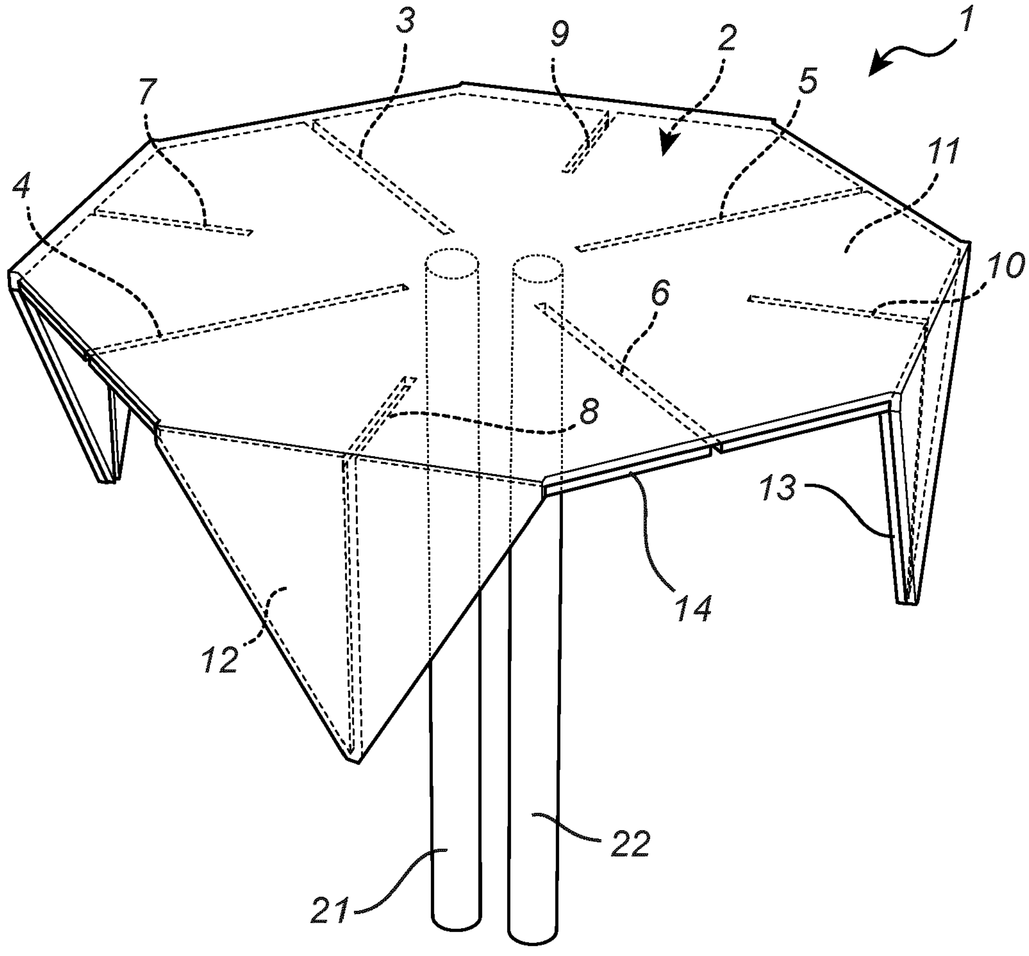

Fig. 8

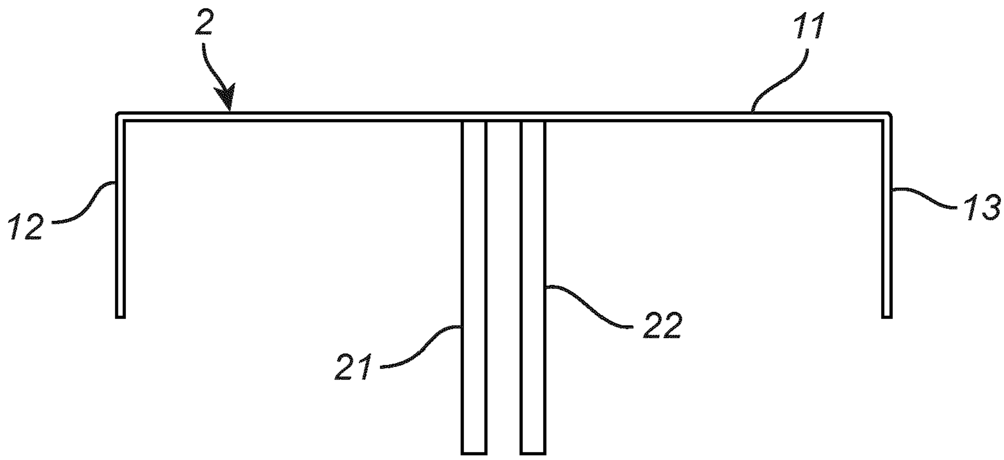

Fig. 9

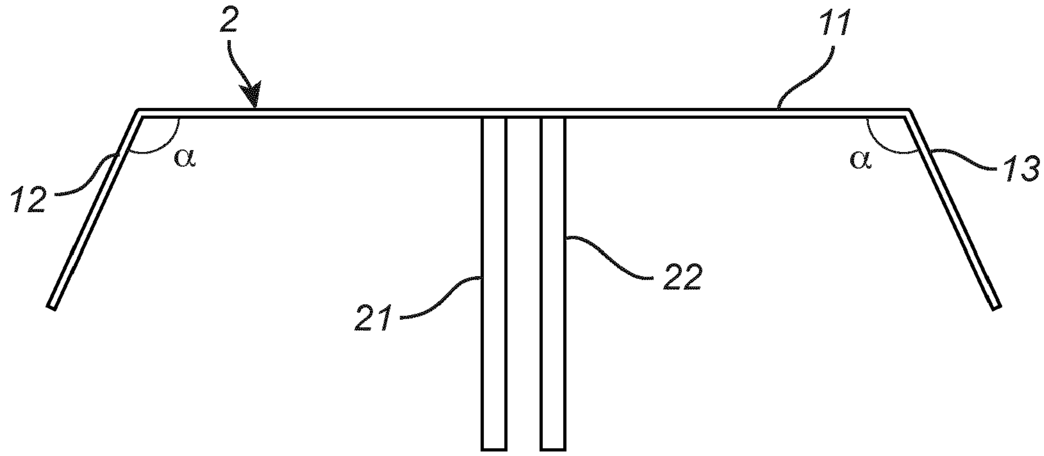

Fig. 10

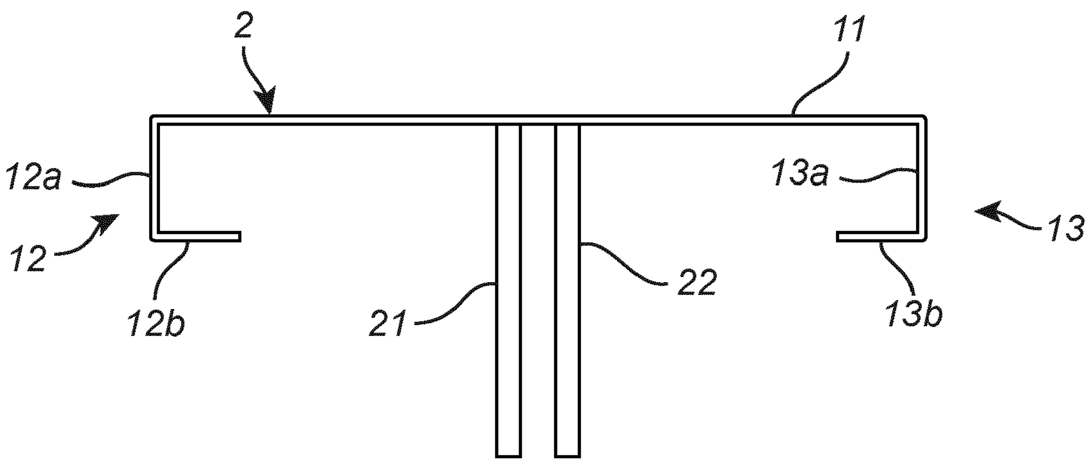

Fig. 11

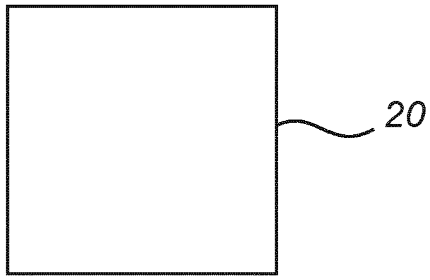

Fig. 12

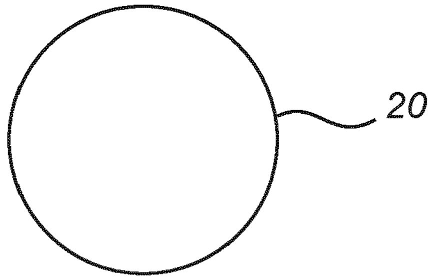

Fig. 14

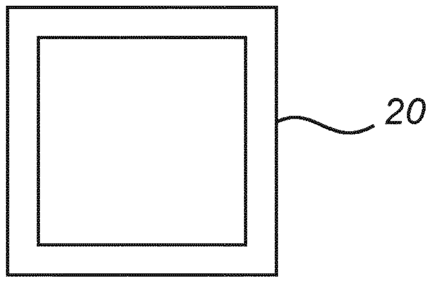

Fig. 13

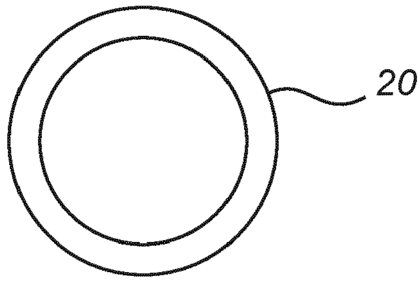

Fig. 15

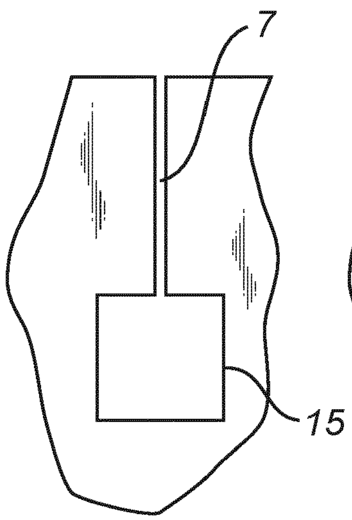

Fig. 16

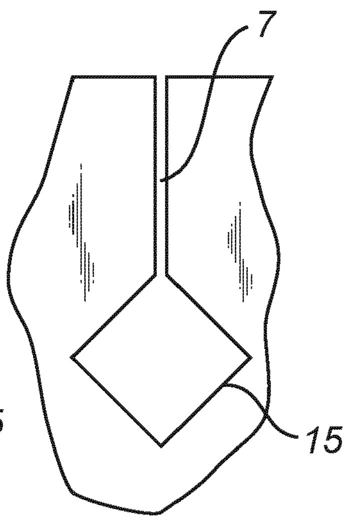

Fig. 17

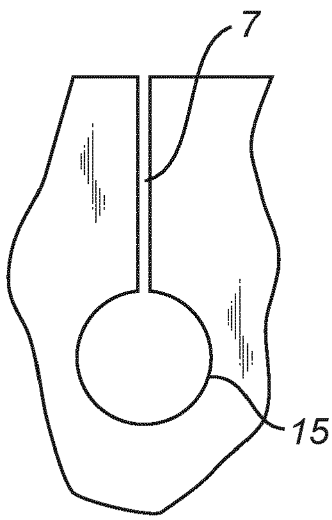

Fig. 18

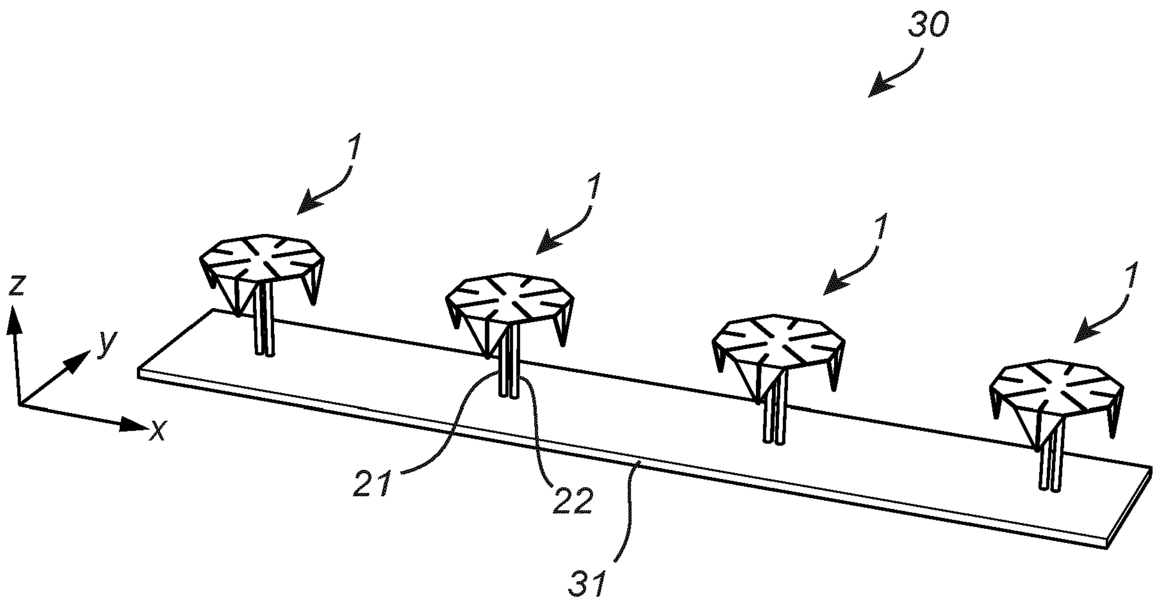

Fig. 19

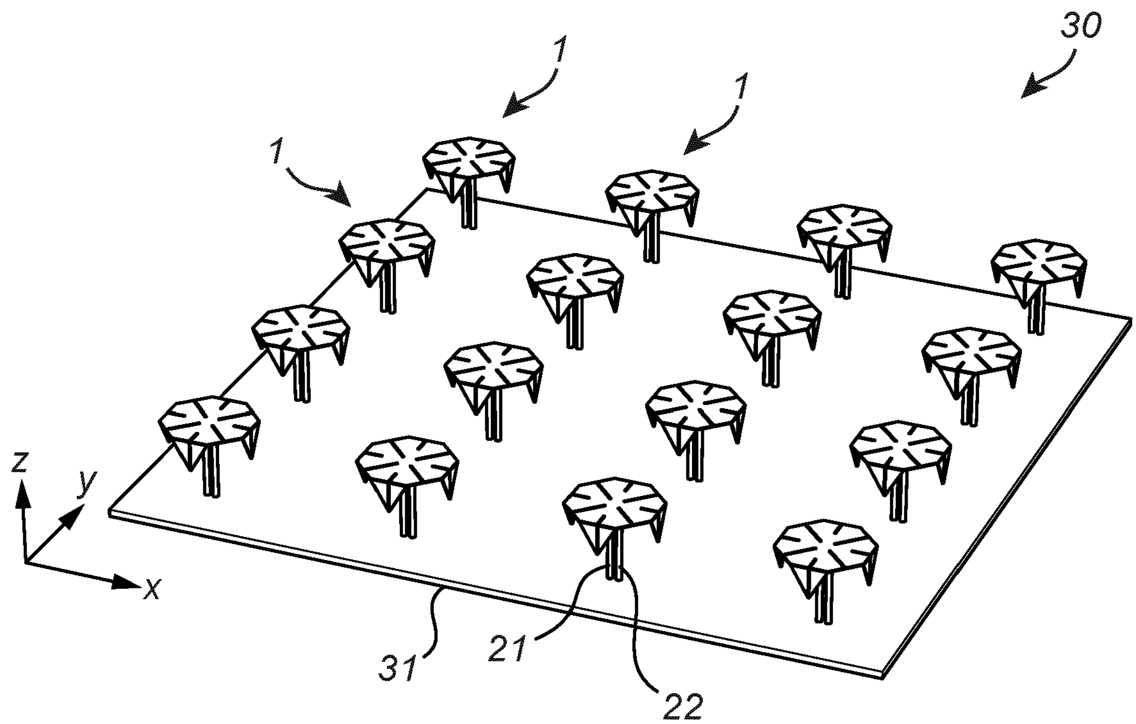

Fig. 20

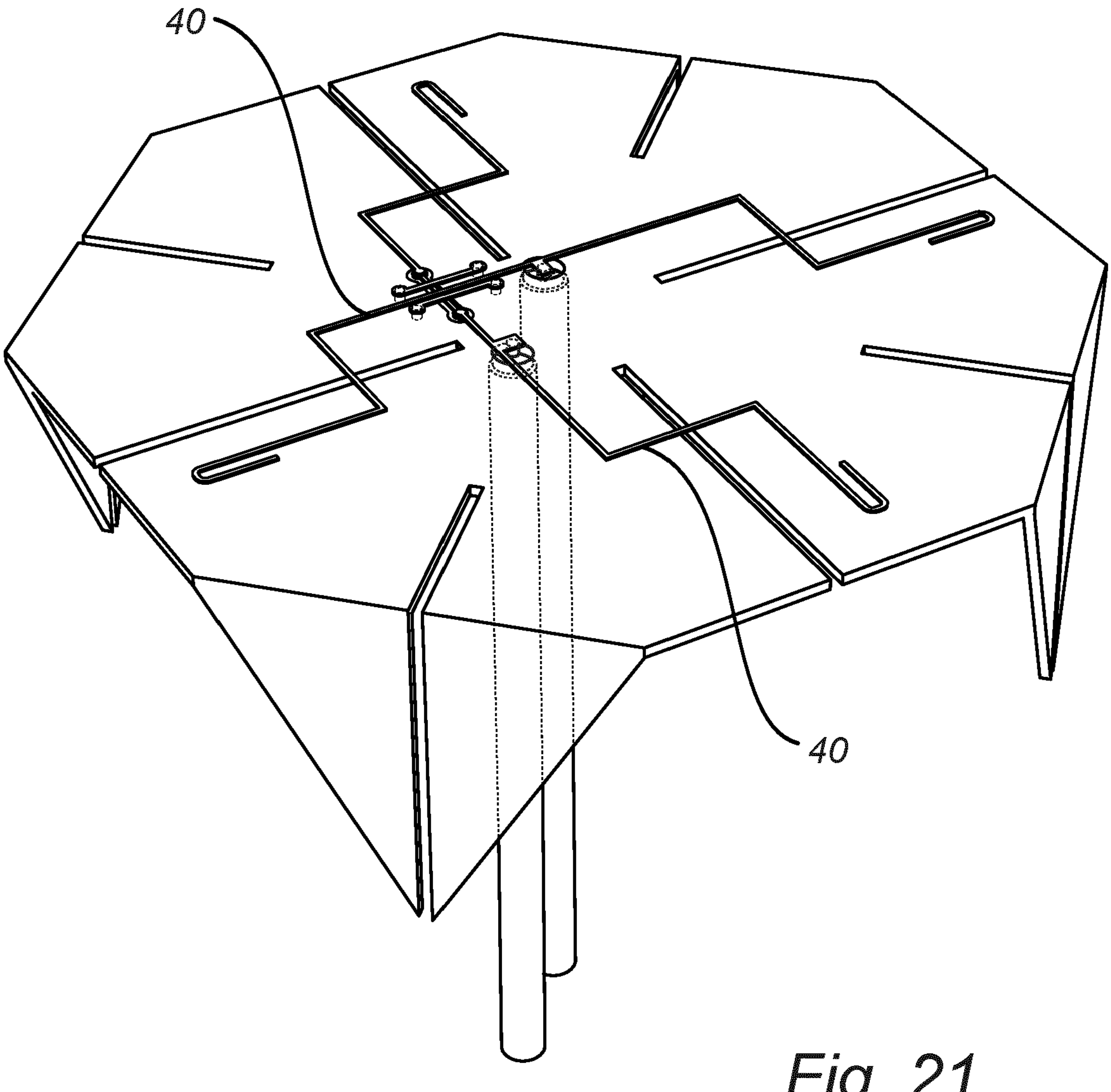

Fig. 21

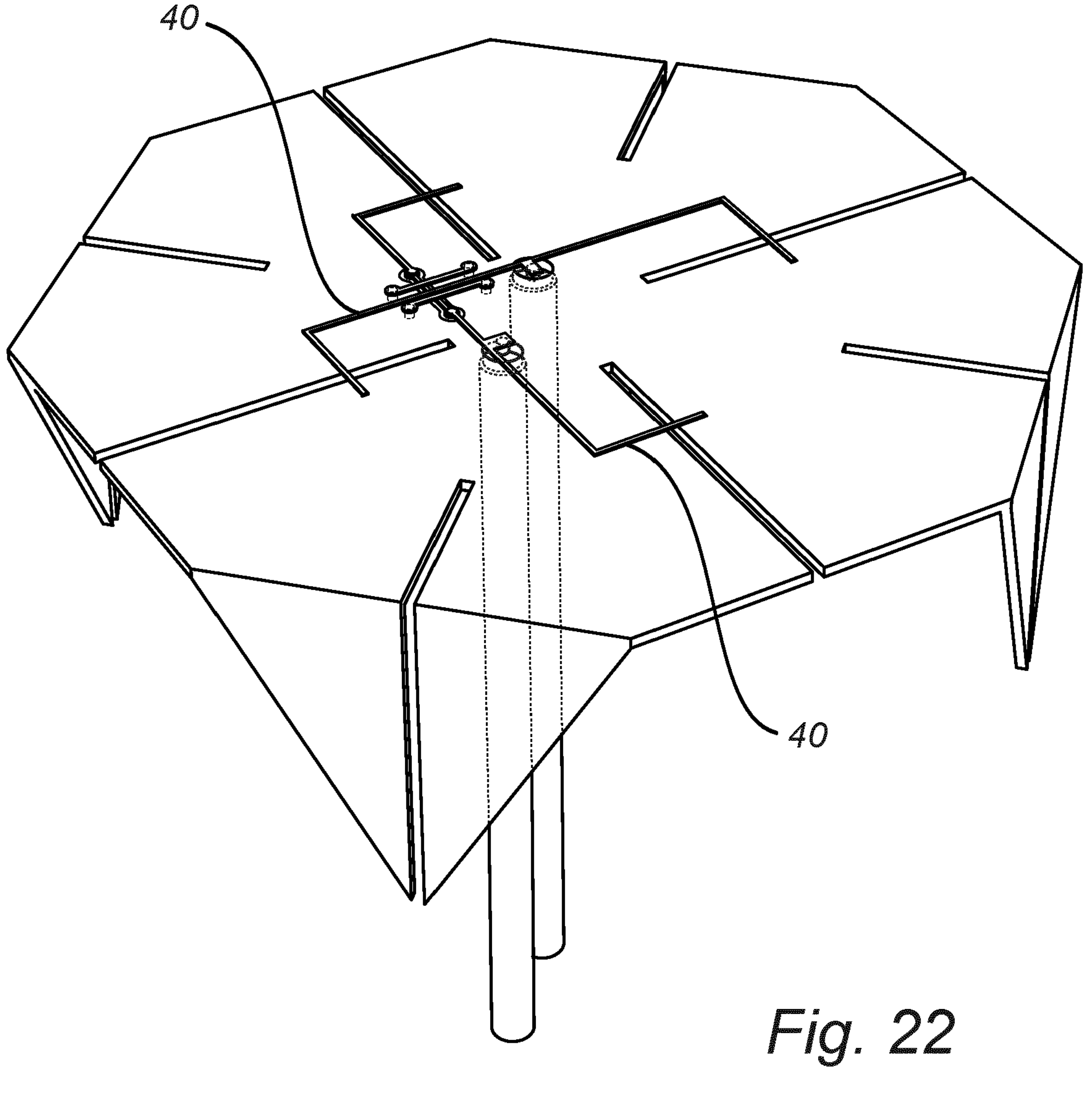

Fig. 22

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EUROPEAN SEARCH REPORT

Application Number
EP 20 18 2886

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	WO 2019/052632 A1 (HUAWEI TECH CO LTD [CN]; GONZALEZ IGNACIO [DE]) 21 March 2019 (2019-03-21) * figures 2,3,6,9,10,23 * * page 1, line 7 - line 12 * * page 13, line 17 - page 15, line 19 * * page 16, line 25 - page 17, line 9 * * page 18, line 1 - line 34 * * page 23, line 27 - page 24, line 5 * -----	1-15	INV. H01Q1/36 H01Q1/48 H01Q5/378 H01Q5/40 H01Q9/04 H01Q13/10 H01Q15/14 H01Q21/24 H01Q21/26
Y	US 2020/044327 A1 (DING CAN [CN] ET AL) 6 February 2020 (2020-02-06) * paragraph [0048] - paragraph [0078]; figures 1-11 * -----	1-15	
Y	WO 2018/077952 A1 (FILTRONIC WIRELESS AB [SE]) 3 May 2018 (2018-05-03) * page 1, line 7 - line 22; figures 1-6 * * page 12, line 24 - page 15, line 16 * * page 16, line 16 - page 18, line 35 * -----	1-7,9-11	
			TECHNICAL FIELDS SEARCHED (IPC)
			H01Q

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
The Hague	10 December 2020	Wattiaux, Véronique

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 20 18 2886

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