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(54) A microwave or millimeter wave RF part using pin grid array (PGA) and/or ball grid array (BGA) technologies

(57) The present invention relates to the technology used to design, integrate and package the radio frequency (RF) part of an antenna system, for use in communication, radar or sensor applications, consisting of components such as waveguide couplers, diplexers, filters, distribution networks, antennas, integrated circuit packages and the like. The invention makes use of pin grid arrays (PGA) and ball grid arrays (BGA) to realize the RF part, based on the principle of gap waveguides. Gap waveguides are formed in the gaps between conducting surfaces. Thereby flat multilayer RF parts can be realized, as well as completely integrated RF front-ends including the packaged MMICs and frequency converters. The PGA and BGA technologies have never before been applied to RF applications.

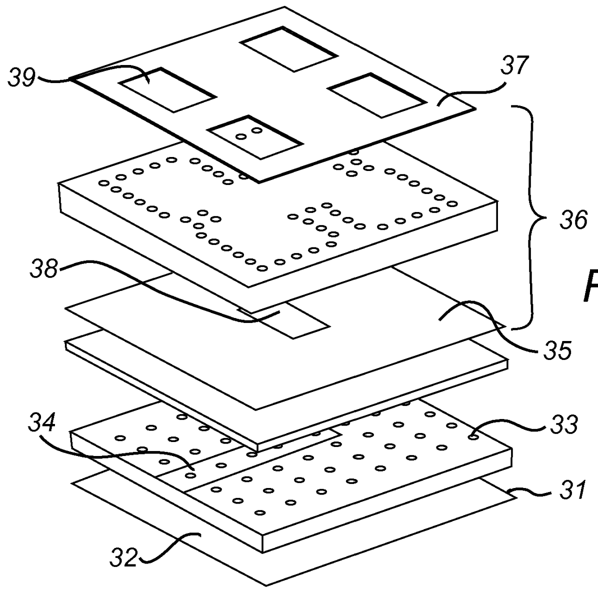

Fig.3a

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Description

Technical field of the invention

[0001] The present invention relates to the technology used to design, integrate and package the radio frequency (RF) part of an antenna system, for use in communication, radar or sensor applications, and e.g. components such as waveguide couplers, diplexers, filters, antennas, integrated circuit packages and the like.

Background

[0002] There is a need for technologies for fast wireless communication in particular at 60 GHz and above, involving high gain antennas, intended for consumer market, so low-cost manufacturability is a must. The consumer market prefers flat antennas, and these can only be realized as flat planar arrays, and the wide bandwidth of these systems require corporate distribution network. This is a completely branched network of lines and power dividers that feed each element of the array with the same phase and amplitude to achieve maximum gain.

[0003] A common type of flat antennas is based on a microstrip antenna technology realized on printed circuits boards (PCB). The PCB technology is well suited for mass production of such compact lightweight corporate-fed antenna arrays, in particular because the components of the corporate distribution network can be miniaturized to fit on one PCB layer together with the microstrip antenna elements. However, such microstrip networks suffer from large losses in both dielectric and conductive parts. The dielectric losses do not depend on the miniaturization, but the conductive losses are very high due to the miniaturization. Unfortunately, the microstrip lines can only be made wider by increasing substrate thickness, and then the microstrip network starts to radiate, and surface waves starts to propagate, both destroying performance severely.

[0004] There is one known PCB-based technology that have low conductive losses and no problems with surface waves and radiation. This is referred to by either of the two names substrate-integrated waveguide (SIW), or post-wall waveguide as in [1]. We will herein use the term SIW only. However, the SIW technology still has significant dielectric losses, and low loss dielectric materials are very expensive and soft, and therefore not suitable for low-cost mass production. Therefore, there is a need for better technologies.

[0005] Thus, there is a need for a flat antenna for high frequencies, such as at or above 60 GHz, and with reduced dielectric losses and problems with radiation and surface waves. In particular, there is a need for a PCB based technology for realizing corporate distribution networks at 60 GHz or above that do not suffer from dielectric losses and problems with radiation and surface waves.

[0006] The gap waveguide technology is based on Prof. Kildal's invention from 2008 & 2009 [2], also described in the introductory paper [3] and validated experimentally in [4]. This patent application as well as the paper [5] describes several types of gap waveguides that can replace microstrip technology, coplanar waveguides, and normal rectangular waveguides in high frequency circuits and antennas.

[0007] The gap waveguides are formed between parallel metal plates. The wave propagation is controlled by means of a texture in one or both of the plates. Waves between the parallel plates are prohibited from propagating in directions where the texture is periodic or quasi-periodic (being characterized by a stopband), and it is enhanced in directions where the texture is smooth like along grooves, ridges and metal strips. These grooves, ridges and metal strips form gap waveguides of three different types: groove, ridge and microstrip gap waveguides [6], as described also in the original patent application [2].

[0008] The texture can be a periodic or quasi-periodic collection of metal posts or pins on a flat metal surface, or of metal patches on a substrate with metalized via-holes connecting them to the ground plane, as proposed in [7] and also described in the original patent application [2]. The patches with via-holes are commonly referred to as mushrooms.

[0009] A suspended (also called inverted) microstrip gap waveguide was presented in [8] and is also inherent in the descriptions in [6] and [7]. This consists of a metal strip that is etched on and suspended by a PCB substrate resting on top of a surface with a regular texture of metal pins. This substrate has no ground plane. The propagating quasi-TEM wave-mode is formed between the metal strip and the upper smooth metal plate, thereby forming a suspended microstrip gap waveguide.

[0010] This waveguide can have low dielectric and conductive losses, but it is not compatible with PCB technology. The textured pin surface could be realized by mushrooms on a PCB, but this then becomes one of two PCB layers to realize the microstrip network, whereby it would be much more costly to produce than gap waveguides realized only using one PCB layer. Also, there are many problems with this technology: It is difficult to find a good wideband way of connecting transmission lines to it from underneath.

[0011] The microstrip gap waveguide with a stopband-texture made of mushrooms were in [9] realized on a single PCB. This PCB-type gap waveguide is called a microstrip ridge gap waveguide, because the metal strip must have via-holes in the same way as the mushrooms.

[0012] A quasi-planar inverted microstrip gap waveguide antenna is described in [10]-[12]. It is expensive both to manufacture the periodic pin array under the microstrip feed network on the substrate located directly upon the pin surface, and the radiating elements which in this case were compact horn antennas.

[0013] A small planar array of 4x4 slots were presented in [13]. The antenna was realized as two PCBs, an upper one with the radiating slots realized as an array of 2x2 subarrays, each consisting of 2x2 slots that are backed by an SIW cavity. Each of the 4 SIW cavities was excited by a coupling slot fed by a microstrip-ridge gap waveguide in the surface of a lower PCB located with an air gap below the upper radiating PCB. It was very expensive to realize the PCBs with sufficient tolerances, and in particular to keep the air gap with constant height. The microstrip-ridge gap waveguide also requires an enormous amount of thin metalized via holes that are very expensive to manufacture. In particular, the drilling is expensive.

[0014] There is therefore a need for a new waveguide and RF packaging technology that have good performance and in addition is cost-efficient to produce.

Summary of the invention

[0015] It is therefore an object of the present invention to alleviate the above-discussed problems, and specifically to provide a new waveguide and RF packaging technology, which has good performance and which is cost-efficient to produce, in particular for use above 30 GHz, and e.g. for use in an antenna system for use in communication, radar or sensor applications.

[0016] According to a first aspect of the invention there is provided an antenna system or radio frequency part of such system, comprising two conducting layers arranged with a gap there between, and a set of periodically or quasi-periodically arranged protruding elements fixedly connected to at least one of said conducting layers, wherein said protruding elements are all electrically connected to each other via said conducting layer on which they are fixedly connected, thereby forming a texture to stop wave propagation - in a frequency band of operation - in other directions than along intended waveguiding paths, wherein said protruding elements are formed as a pin grid array and/or a ball grid array.

[0017] By RF part is in the context of the present application meant a part of an antenna system used in the radio frequency transmitting and/or receiving sections of the antenna system, sections which are commonly referred to as the front end or RF front end of the antenna system. The RF part may be a separate part/device connected to other components of the antenna system, or may form an integrated part of the antenna system or other parts of the antenna system.

[0018] The waveguide and RF packaging technology of the present invention may be realized by using PCB technology or similar, and is in particular suitable for realizing a wideband and efficient flat planar array antenna. However, it may also be used for other parts of the antenna system, such as waveguides, filters, integrated circuit packaging and the like, and in particular for integration and RF packaging of such parts into a complete RF front-end or antenna system.

[0019] As discussed in the foregoing, the groove gap waveguide, the microstrip ridge gap waveguide and the inverted microstrip gap waveguide, have already been demonstrated to work and have lower loss than conventional microstrip lines and coplanar waveguides. The present inventors have now found that similar or better performance can be obtained in a much more cost-effective way by using pin grid array and/or ball grid array technology. Hereby, it is e.g. possible to realize corporate distribution networks at low manufacturing cost and to sufficient accuracy at 60 GHz and higher frequencies.

[0020] A metal pin grid array, often abbreviated PGA, is per se known, and refers to a type of integrated circuit packaging that is used in particular for packaging of microprocessor. In conventional PGA technology, the package is square or rectangular, and the pins are arranged in a regular array on the underside of the package. The pins are commonly spaced 2.54 mm (0.1 ") apart, and may or may not cover the entire underside of the package. The locations of the pins as well as the sizes and periods of them can be specified by the customer. Such PGAs can also be made in metallized plastic, abbreviated PPGA, or in metalized ceramics, abbreviated CPGA.

[0021] PGAs are often mounted on PCBs using the through hole method or inserted into a socket. The PGA can also be mounted on and soldered to the conducting surface of a PCB or on the surface of a metal plate. PGAs allow for more pins per integrated circuit than older packages such as dual in-line package (DIP). The pins can also have the shape of balls, in which case the technology is called Ball Grid Array (BGA).

[0022] It has now been realized that such PGA, PPGA, CPGA and BGA technologies can be used to manufacture the pin surfaces of gap waveguides for a very low price compared to conventional milling of metal plates, and also compared to drilling via holes in a dielectric substrate.

[0023] The PGA, PPGA, CPGA and BGA have never before been used as part of a waveguide to guide waves, and never for RF packaging either. Also, antenna specialists do not generally know about the PGA technology, and only a few PCB manufacturers can provide PGA or BGA.

[0024] The PGAs are traditionally used to provide conductive connections between many ports of a microprocessor (that is located on one PCB) to the corresponding number of ports on another PCB that can be above or below the first PCB. In this case one PCB contains the PGA, and the other PCB contains a corresponding socket with metalized holes fitting to the locations of all pins of the PGA. Then, each pin represents one port of the upper PCB, and each metalized hole represents one port of the lower PCB. Thus, each pin and each socket hole are electrically isolated from each other and represent individual electric ports of the microprocessor on the first PCB.

[0025] On the contrary, when PGAs are used for realizing gap waveguides and RF packaging and the like in accordance with the present invention, the pins are connected electrically with each other via the conducting layer, such as a metal plate or PCB, on which they are mounted. Thus, they are not electrically isolated from each other at the points of fixation to the PCB or metal plate. This is very different from how PGAs normally are used. Previously known PGAs mounted on PCBs ensures that each pin is isolated, i.e. there is no conductive or metal connection between them at their bases. When PGAs are used to form waveguides and the like in accordance with the present invention, there will be conductive metal contact between neighboring pins on the plate at which they are mounted.

[0026] Thus, in the present invention, the protruding elements are formed by the same process as pin grid array and/or a ball grid array used to connect and package digital microprocessors to printed circuit boards, wherein each pin is fixed to the conducting layer by soldering, but, contrary to such known applications of PGA/BGA, all pins are connected electrically to each other at their bases on the conductive layer.

[0027] The quasi-periodic protruding elements of the textured surface are realized by using PGA or BGA technology of any kind, i.e they can also be PPGA or CPGA.

[0028] The PGA or BGA technology is preferably used to realize a waveguide, a groove gap waveguide or a ridge gap waveguide component, or it is used to package microstrip-based circuits and RF integrated circuits such as low noise amplifiers for receiving RF signals and or power amplifiers for transmitting RF signals, or to integrate and package such components and circuits in one package. The PGA gap waveguides may form a distribution network for an array antenna, and they may even be used to form the radiating elements of the array. Thereby, the complete package may represent a complete antenna system.

[0029] In one embodiment the protruding elements may further be in contact with, and preferably fixedly connected to, also the other conducting layer, wherein the protruding elements are arranged to at least partly provide the walls of a tunnel or a cavity connecting said conducting layers across the gap between them, said tunnel thereby functioning as a waveguide or a waveguide cavity. Thus, in this embodiment, a smooth upper plate (conducting layer) can also rest on the PGA and/or BGA or on some part of it, and the protruding elements/pins that provide the support can e.g. be soldered to the upper smooth metal plate (conducting layer) by baking the construction in an oven. Thereby, it is possible to form post-wall waveguides as described in [1], said documents hereby being incorporated in its entirety by reference, but without any substrate inside the waveguide. Thus, SIW waveguides are provided without the substrate so to say. Such waveguide technologies may be referred to as PGA rectangular waveguide technology, in contrast to the PGA gap waveguide technology, involving PGA and/or BGA arranged on one of the metal surfaces and not connected to the metal surface on the other side of the gap. The PGA rectangular waveguide technology is advantageous compared to conventional SIW because it reduces the dielectric losses, since there is no substrate inside the waveguide, and the PGA rectangular waveguides can also be produced more cost-effectively, and since the use of expensive lowloss substrate material may now be reduced or even omitted.

[0030] Further, the waveguide and RF packaging technology may be a PGA gap waveguide, and further comprising at least one groove, ridge or microstrip along which waves are allowed to propagate. The microstrip may be arranged as a suspended microstrip.

[0031] In a PGA gap waveguide, the protruding elements forming said texture to stop wave propagation, are preferably only in contact with one of the conducting layers.

[0032] In a PGA gap waveguide, the waves propagate mainly in the air gap between the waveguiding structure and the smooth metal surface. The gap can also be filled fully or partly by dielectric material, of mechanical reasons to keep the gap of constant height. The gap can even have metal elements for mechanically supporting the gap at constant height. These metal elements are then located outside the traces of the waveguiding structure. The periodic or quasi-periodic protruding elements in the textured surface are preferably provided on both sides of the waveguiding elements, and these are designed to stop waves from propagating between the two metal surfaces, in other directions than along the waveguiding structure. The frequency band of this forbidden propagation is called the stopband, and this defines the maximum available operational bandwidth of the gap waveguide.

[0033] The PGA gap waveguide may form the distribution network of an array antenna. The distribution network is preferably fully or partly corporate containing power dividers and transmission lines, realized fully or partly as a gap waveguide, i.e. formed in the gap between one smooth and one textured surface, including either a ridge gap waveguide, groove gap waveguide and/or a microstrip gap waveguide, depending on whether the waveguiding structure in the textured surface is a metal ridge, groove or conducting strip on a thin dielectric substrate. The latter can be an inverted microstrip gap waveguide, or a microstrip-ridge gap waveguide as defined by known technology.

[0034] In a distribution network, the waveguiding PGA structure may be formed like a tree to become a branched or corporate distribution network by means of power dividers and lines between them. The pins surrounding the waveguiding groove, ridge or metal strip are fastened to the supporting metal plate or metallized substrate by the same production procedure as the pins or balls of a PGA and/or BGA. This procedure can involve tools like a stencil for producing the pattern of the layout of the pins and other elements like the waveguiding structure, and a jig for holding all parts in position before being soldered to the supporting conducting plate in an oven.

[0035] The protruding elements, or pins, of the PGA and/or BGA may have any cross-sectional shape, but preferably have a square, rectangular or circular cross-sectional shape. Further, the protruding elements preferably have maximum cross-sectional dimensions of smaller than half a wavelength in air at the operating frequency. Preferably, the maximum dimension is much smaller than this. The maximum cross-sectional dimension is the diameter in case of a circular cross-section, or diagonal in case of a square or rectangular cross-section.

[0036] Also, the protruding elements in the texture stopping wave propagation are preferably spaced apart by a spacing being smaller than half a wavelength in air at the operating frequency. This means that the separation between any pair of adjacent protruding elements in the texture is smaller than half a wavelength.

[0037] In a preferred embodiment, the protruding elements forming said texture to stop wave propagation are formed as a pin grid array. Further, a ball grid array may be arranged outside the protruding elements forming said texture to stop wave propagation, said ball grid array functioning as spacers between said conducting layers. Thus, the BGA elements are here used as spacers between the smooth and textured metal plates, e.g. to ensure a constant and well-defined height of the gap between the two surfaces. Then, the elements of the PGA and BGA are located at positions where it does not make any blockage or in other ways harm the wave propagation within the gap.

[0038] At least one of the conducting layers may further be provided with at least one opening, preferably in the form of rectangular slot(s), said opening(s) allowing radiation to be transmitted to and/or received from said PGA rectangular waveguide or PGA gap waveguide. Such an opening may be used either as radiating openings in an array antenna, or as a coupling opening to transfer radiation to another layer of the antenna system. The openings may preferably be arranged in the smooth metal surface of the PGA gap waveguide, i.e. in the conducting layer not being provided with the protruding elements, and the slots may be arranged to radiate directly from its upper side, in which case the spacing between each slot preferably is smaller than one wavelength in free space.

[0039] The antenna system may further comprise horn shaped elements connected to the openings in the metal surface of the PGA rectangular waveguide or PGA gap waveguide. Such slots are coupling slots that make a coupling to an array of horn-shaped elements which are preferably located side-by-side in an array in the upper metal plate/conducting layer. The diameter of each horn element is preferably larger than one wavelength. An example of such horn array is per se described in [10], said document hereby being incorporated in its entirety by reference.

[0040] When several slots are used as radiating elements in the upper plate, the spacing between the slots is preferably smaller than one wavelength in air at the operational frequency.

[0041] The slots in the upper plate may also have a spacing larger than one wavelength. Then, the slots are coupling slots, which makes a coupling from the ends of a distribution network arranged in the textured surface to a continuation of this distribution network in a layer above it, that divides the power equally into an array of additional slots that together form a radiating an array of subarray of slots, wherein the spacing between each slot of each subarray preferably is smaller than one wavelength. Hereby, the distribution network may be arranged in several layers, thereby obtaining a very compact assembly. For example, a first PCB may form a PGA rectangular waveguide or a PGA waveguide therein, in the aforementioned way, and a second PCB may be arranged on top of this first PCB. A conducting layer separating the first and second PCB, and e.g. being arranged as a ground plane of the second PCB, may comprise the coupling slots. Each of which make a coupling from each ends of the distribution network on the textured surface to a continuation of this distribution network that divides the power equally into a small array of slots formed in a conducting layer arranged at the upper side of the second PCB, that together form a radiating subarray of the whole array antenna. The spacing between each slot of the subarray is preferably smaller than one wavelength.

[0042] Thus, the RF part may comprise two PCBs, wherein at least one first coupling slot is provided in a conducting layer separating the first and second PCB, and forming a radiating connection between a waveguide structure formed by the texture in the first PCB with a waveguide structure formed by the texture in the second PCB, and wherein an upper conducting layer of the second PCB is further provided with a plurality of radiating second openings. The second PCB may form a SIW cavity between the upper and lower conducting layers, said SIW cavity realizing a distribution network. Further, the second PCB may or may not have a dielectric substrate arranged between the upper and lower conducting layers. If no such dielectric substrate is provided, connection of the two conducting layers together may be realized by a PGA and/or BGA in terms of PGA waveguide cavities, as discussed in the foregoing.

[0043] There may be a strong mutual E-plane coupling between the subarrays discussed above. This coupling, when present, makes it difficult to impedance match the antenna at the subarray ports, and this limits the performance of the whole antenna system. To this end, the RF part may further comprise at least one long slot between the subarrays in E-plane. Introducing one or more such parallel long slots between the subarrays in E-plane effectively reduces the mutual coupling. Each slot must be surrounded by pins in the form of PGA on both sides. The pins thereby work as walls below the slots, so that each long slot will become like a groove and work like part of a corrugated surface. These elongate slots working as corrugations may be as long as the whole antenna, or it may be divided in shorter parts. The performance of corrugated surfaces is per se known from Prof. Kildal's early works of soft and hard surfaces. The transversely corrugated socalled "soft" surface stops waves from propagating and thereby reduce the mutual coupling between the radiating slots of neighboring subarrays.

[0044] The distribution network is at the feed point preferably connected to the rest of the RF front-end containing duplexer filters to separate the transmitting and receiving frequency bands, and thereafter transmitting and receiving amplifiers and other electronics. The latter are also referred to as converter modules for transmiting and receiving. These parts may be located beside the antenna array on the same surface as the texture (PGA or BGA) forming the distribution network, or below it. A transition is preferably provided from the distribution network to the duplexer filter, and this may be realized with a hole in the ground plane of the lower PCB (or in the lower metal plate) and forming a rectangular waveguide interface on the backside of it. Such rectangular waveguide interface can also be used for measurement purposes.

[0045] At least one of the conducting layers may be arranged on a printed circuit board. As discussed in relation to a specific embodiment above, the conducting layers may also be arranged on two different printed circuit boards.

[0046] The antenna system may further comprise a surrounding frame connecting the two conducting layers together in the vicinity of the edges of said layers, e.g. at the rim of the PCB(s). This may e.g. be used to protect the interior of the RF part from contamination and the like, and may also be useful to ensure that a constant height of the gap is provided.

[0047] The antenna system may also comprise at least one integrated circuit arranged between two of the conducting layers of the waveguide and RF packaging technology, the texture to stop wave propagation thereby removing resonances in the cavity inside which said integrated circuit(s) is located. In a preferred such embodiment, the at least one integrated circuit is a monolithic microwave integrated circuit (MMIC).

[0048] Preferably, the integrated circuit(s) is arranged on a conducting layer not being provided with said protruding elements, and wherein protruding elements overlying the integrated circuit(s) are shorter than protruding elements not overlying said integrated circuit(s). Hereby, the integrated circuit(s) may be somewhat embraced by the protruding elements, thereby providing enhanced shielding and protection. However, the protruding elements are preferably not in contact with the integrated circuit(s), and also preferably not in contact with the conducting layer on which the integrated circuit(s) is arranged.

[0049] According to another aspect of the invention, there is provided a flat array antenna comprising a corporate distribution network realized by a RF part in accordance with the discussion above.

[0050] Hereby, similar embodiments and advantages as discussed above are feasible.

[0051] Preferably, the corporate distribution network forms a branched tree with power dividers and waveguide lines between them. This may e.g. be realized as PGA gap waveguides and/or PGA rectangular waveguides as discussed in the foregoing.

[0052] The antenna may also be an assembly of a plurality of sub-assemblies, in the way already discussed in the forgoing, whereby the total radiating surface of the antenna is formed by the combination of the radiating sub-assembly surfaces of the sub-assemblies. Each such sub-assembly surface may be provided with an array of radiating slot openings, as discussed in the foregoing. The sub-assembly surfaces may e.g. be arranged in a side-by-side arrangement, to form a square or rectangular radiating surface of the assembly. Preferably, one or more elongated slots working as corrugations are further arranged between the sub-arrays, i.e. between the sub-assembly surfaces, in the E-plane.

[0053] According to still another embodiment, there is provided a method for producing an antenna system, e.g. for use in a communication, radar or sensor system, comprising several and at least two conducting layers having a narrow gap between them over most of their surfaces:

providing any first of two such conducting layers;
fixedly connecting a set of periodically or quasi-periodically arranged protruding elements to the first conducting layer, wherein said protruding elements are all electrically connected to each other via said conducting layer on which they are fixedly connected, and wherein said protruding elements are formed by pin grid array and/or ball grid array technology; and
providing a second of two such conducting layer overlying said first conducting layer, so that a gap is formed there between;
wherein the protruding elements form a texture to stop wave propagation in a frequency band of operation in other directions than along intended waveguiding paths within said gap.

[0054] Hereby, similar embodiments and advantages as discussed above are feasible.

[0055] In one line of embodiments, the second conducting layer is arranged in contact with at least some of the protruding elements of the first conducing layer, and connected to said protruding elements, e.g. by soldering. Thus, the smooth surface of the second conducting layer can be laid to rest on the PGA and/or BGA or on some part of it, and the protruding elements/pins that provide the support can be soldered to the upper smooth metal plate by baking the construction in an oven. Hereby, it is possible to form post-wall waveguides as described in [1], as discussed in the previous, but without any substrate inside the waveguide. Thus, as also discussed in the foregoing, SIW waveguides without substrate(s) are provided, which may be referred to as PGA rectangular waveguide technology, in contrast to the PGA gap waveguide technology.

[0056] However, connection of the two conducting layers together may also be accomplished in other ways, such as e.g. connecting the layers together by means of a surrounding frame or the like.

[0057] The step of providing protruding elements on the first conducting layer preferably involves the steps of:

producing a pattern of the layout of the protruding elements and possible waveguide paths on the first conducting layer;
arranging the parts to be connected to the first conducting layer in a jig; and
connecting the parts to the first conducting layer.

[0058] Further, the step of connecting the parts to the first conducting layer preferably comprises soldering the parts to the conducting layer during heat treatment.

[0059] The ridge gap waveguide makes use of a ridge between the pins to guide the waves. Such ridges may also be used in connection with PGA technology. Then, this waveguiding ridge structure, which may have the form of a tree if it is used to realize a branched distribution network, can be mounted in between the pins and fastened to the supporting metal plate or metallized substrate by the same production procedure like the pins or balls. This procedure can involve tools like a stencil for producing the pattern of the layout of the pins and other elements like the waveguiding ridge structure, and a jig for holding all parts in position before being soldered to the supporting conducting plate in an oven.

[0060] The present invention may be summarized as:

a) A radio frequency (RF) part of an antenna system, e.g. for use in communication, radar or sensor applications, comprising at least two conducting layers arranged with a gap there between, and a set of periodically or quasi-periodically arranged protruding elements fixedly connected to at least one of said conducting layers, thereby forming a texture to stop wave propagation in a frequency band of operation in other directions than along intended waveguiding paths, wherein said protruding elements are formed as a pin grid array and/or a ball grid array, wherein each pin is fixed to the conducting layer by soldering, but wherein all protruding elements are connected electrically to each other at their bases via said conductive layer on which they are fixedly connected.

b) The RF part may be a waveguide, and wherein the protruding elements are further in contact with, and preferably fixedly connected to, also the other conducting layer, and wherein the protruding elements are arranged to at least partly surround a cavity between said conducting layers, said cavity thereby functioning as a waveguide.

c) The RF part may be a gap waveguide, and further comprising at least one groove, ridge or microstrip line along which waves are to propagate.

d) The microstrip line in c) may be arranged as a suspended microstrip.

e) In the RF part, the protruding elements may have have a square, rectangular or circular cross-sectional shape.

f) In the RF part, the protruding elements may have maximum cross-sectional dimensions of less than half a wavelength in air at the operating frequency.

g) In the RF part, the protruding elements in the texture stopping wave propagation may be spaced apart by a spacing being smaller than half a wavelength in air at the operating frequency.

h) In the RF part, the protruding elements forming said texture to stop wave propagation may be formed as a pin grid array.

i) The RF part may further comprise a ball grid array arranged outside the protruding elements forming said texture to stop wave propagation, said ball grid array functioning as spacers between said conducting layers.

j) In the RF part, the protruding elements forming said texture to stop wave propagation may be only in contact with one of the conducting layers.

k) In the RF part, at least one of the conducting layers may be provided with at least one opening, preferably in the form of rectangular slot(s), said opening(s) allowing radiation to be transmitted to and/or received from said RF part.

l) The RF part of k) may further comprise horn shaped elements connected to the openings.

m) The spacing between the slots in l) or k) may be smaller than one wavelength in air at the operational frequency.

n) At least one of said slots in l), k) or m) may be a coupling slot, which make a coupling from an end of a distribution network arranged in the textured surface to a continuation of this distribution network that divides the power equally into an array of additional slots that together form a radiating subarray of an array antenna, wherein the spacing between each slot of the subarray preferably is smaller than one wavelength.

o) The RF part in n) may comprise two PCBs, wherein at least one first coupling slot is provided in a conducting layer separating the first and second PCB, and forming a radiating connection between a waveguide structure formed by the texture in the first PCB with a waveguide structure formed by the texture in the second PCB, and wherein an upper conducting layer of the second PCB is further provided with a plurality of radiating second openings.

p) In the RF part of o) the second PCB may form a SIW cavity between the upper and lower conducting layers, said SIW cavity realizing a distribution network.

q) In the RF part of o) or p), wherein the second PCB may not have any dielectric substrate arranged between the upper and lower conducting layers and the via holes of the SIW cavity may instead be PGA pins defining the walls of the cavity.

r) The RF part as in n), o), p) or q) may further comprise at least one corrugation between the subarrays in E-plane, realized by an elongated slot in the upper metal plate and pins on the form of metalized via holes or PGA along both sides of the slots.
s) In the RF part at least one of said conducting layers may be arranged on a printed circuit board.
t) In the RF part said conducting layers may be arranged on two different printed circuit boards.
u) The RF part may further comprise a surrounding frame connecting the two conducting layers together in the vicinity of the edges of said layers.
v) The RF part may further comprise at least one integrated circuit module arranged between said conducting layers, the texture to stop wave propagation thereby functioning as a means of removing resonances within the package for said integrated circuit module(s).
w) In the RF part of v) the at least one integrated circuit may be a monolithic microwave integrated circuit.
x) In the RF part of v) or w), the integrated circuit module(s) may be arranged on a conducting layer not being provided with said protruding elements, and wherein protruding elements overlying the integrated circuit(s) are shorter than protruding elements not overlying said integrated circuit(s).
y) A flat array antenna comprising a corporate distribution network realized by an RF part in accordance with any of a)-y, or any combinations thereof.
z) In the antenna of y), the corporate distribution network may form a branched tree with power dividers and waveguide lines between them.
aa)A method for producing an RF part of an antenna system, e.g. for use in communication, radar or sensor applications, comprising:

providing a first conducting layer;
fixedly connecting a set of periodically or quasi-periodically arranged protruding elements to the first conducting layer, wherein said protruding elements are all electrically connected to each other via said conducting layer on which they are fixedly connected, and wherein said protruding elements are formed by pin grid array and/or ball grid array technology; and
providing a second conducting layer overlying said first conducting layer, so that a gap is formed there between;
wherein the protruding elements forms a texture to stop wave propagation in a frequency band of operation in other directions than along intended waveguiding paths within said gap.

bb)In the method of aa), the second conducting layer may be arranged in contact with at least some of the protruding elements of the first conducing layer, and connected to said protruding elements, e.g. by soldering.
cc)In the method of aa) or bb), the step of providing protruding elements on the first conducting layer may involve the steps of:
producing a pattern of the layout of the protruding elements and possible waveguide paths on the first conducting layer;
arranging the parts to be connected to the first conducting layer in a jig; and
connecting the parts to the first conducting layer.
dd)In the method of cc), the step of connecting the parts to the first conducting layer may comprise soldering the parts to the conducting layer during heat treatment.

[0061] These and other features and advantages of the present invention will in the following be further clarified with reference to the embodiments described hereinafter. Notably, the invention is in the foregoing described in terms of a terminology implying a transmitting antenna, but naturally the same antenna may also be used for receiving, or both receiving and transmitting electromagnetic waves. The performance of the part of the antenna system that only contains passive components is the same for both transmission and reception, as a result of reciprocity. Thus, any terms used to describe the antenna above should be construed broadly, allowing electromagnetic radiation to be transferred in any or both directions. E.g., the term distribution network should not be construed solely for use in a transmitting antenna, but may also function as a combination network for use in a receiving antenna.

Brief description of the drawings

[0062] For exemplifying purposes, the invention will be described in closer detail in the following with reference to embodiments thereof illustrated in the attached drawings, wherein:

Fig 1 is a perspective side view showing a rectangular PGA rectangular waveguide in accordance with one embodiment of the present invention;
Fig 2 is a perspective side view showing a circular cavity of a PGA rectangular waveguide in accordance with another embodiment of the present invention;
Fig 3 is a schematic illustration of an array antenna in accordance with another embodiment of the present invention, where Fig. 3a is an exploded view of a subarray/sub-assembly of said antenna, Fig. 3b is a perspective view of an antenna comprising four such subarrays/sub-assemblies, and Fig. 3c is a perspective view of an alternative way of realizing the antenna of Fig. 3b;
Fig 4 is a top view of an exemplary distribution network realized in accordance with the present invention, and useable e.g. in the antenna of Fig. 3;

Fig 5 is a perspective and exploded view of three different layers of an antenna in accordance with another alternative embodiment of the present invention making use of a PGA inverted microstrip gap waveguide;

Fig 6 is a close-up view of an input port of a ridge gap waveguide in accordance with a further embodiment of the present invention;

Figs 7 and 8 are perspective views of partly disassembled gap waveguide filters in accordance with a further embodiments of the present invention; and

Fig 9 is an illustration of a PGA gap waveguide packaged MMIC amplifier chains, in accordance with a further embodiment of the present invention, and where Fig. 9a is a schematic perspective view seen from the side and Fig 9b is a side view.

Detailed description of preferred embodiments

[0063] In the following detailed description, preferred embodiments of the present invention will be described. However, it is to be understood that features of the different embodiments are exchangeable between the embodiments and may be combined in different ways, unless anything else is specifically indicated. Even though in the following description, numerous specific details are set forth to provide a more thorough understanding of e present invention, it will be apparent to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known constructions or functions are not described in detail, so as not to obscure the present invention.

[0064] In a first embodiment, as illustrated in Fig. 1, an example of a PGA rectangular waveguide is illustrated. The waveguide comprises a first conducting layer 1, and a second conducting layer 2 (here made semitransparent, for increased visibility). The conducting layers are arranged at a constant distance h from each other, thereby forming a gap there between.

[0065] This waveguide resembles a conventional SIW with metallized via holes in a PCB with metal layer (ground) on both sides, upper (top) and lower (bottom) ground plane. However, here there is no dielectric substrate between the conducting layers, and the metalized via holes are replaced with a PGA, forming protruding elements 3 extending from, and fixedly connected to, the first conducting layer. The second conducting layer 2 rest on the protruding elements 3, and is also connected to these, e.g. by means of soldering. The protruding elements 3 are made of conducting material, such as metal. They can also be made of metallized plastics or ceramics.

[0066] Similar to a SIW waveguide, a waveguide is here formed between the conducting elements, here extending between the first and second ports 4.

[0067] In this example, a very simple, straight waveguide is illustrated. However, more complicated paths may be realized in the same way, including curves, branches, etc.

[0068] Fig 2 illustrates a circular cavity of a PGA rectangular waveguide. This is realized in a similar way as in the above-discussed straight waveguide of Fig. 1, and comprises first and second conducting layers 1, 2, arranged with a gap there between, and protruding PGA elements extending between the conducting layers, and connected to these layers. The protruding elements 3 are here arranged along a circular path, enclosing a circular cavity. Further, in this exemplary embodiment, a feeding arrangement 6 and a X-shaped radiating slot opening 5 is provided.

[0069] This circular waveguide cavity functions in similar ways as circular SIW cavity.

[0070] With reference to Fig 3, an embodiment of a flat array antenna will now be discussed. This antenna structurally and functionally resembles the antenna discussed in [13], said document hereby being incorporated in its entirety by reference.

[0071] Fig 3a shows the multilayer structure of a subassembly in an exploded view. The sub-assembly comprises a lower PCB 31 with a first ground plane/conducting layer 32, and a texture formed by protruding PGA elements 33 and a ridge structure 34, together forming PGA gap waveguide between the first ground place 32 and a second ground plane/conducting layer 35. The second ground plane 35 is here arranged on a second, upper PCB 36, which also comprises a third, upper ground plane/conducting layer 37. A gap is thus formed between both the first and second ground planes and between the second and third ground planes, respectively, thereby forming two layers of waveguides. The bottom, second ground plane 35 of the upper PCB has a coupling slot 38, and the upper one has 4 radiating slots 39, and between the two ground planes there is a PGA rectangular waveguide cavity. Fig. 3a shows only a single subarray forming the unit cell (element) of a large array. Fig 3b shows an array of 4 such subarrays, arranged side-by-side in a rectangular configuration. There may be even larger arrays of such subarrays to form a more directive antenna.

[0072] Between the subarrays, there is in one direction provided a separation, thereby forming elongated slots in the upper metal plate. Pins are arranged along both sides of the slots. This forms corrugations between the subarrays in E-plane.

[0073] In Fig 3c, an alternative embodiment is shown, in which the upper conducting layer, including several sub-arrays, is formed as a continuous metal plate. This metal plate preferably has a thickness sufficient to allow grooves to be formed in it. Hereby, elongate corrugations having similar effects as the slots in Fig 3b can instead be realized as elongate grooves extending between the unit cells.

[0074] Either or both of the waveguide layers between the first and second conducting layer and the second and third conducting layer, respectively, may be made as a PGA waveguide or a PGA rectangular waveguide as discussed in the foregoing, without any substrate between the two metal ground planes, and with protruding PGA elements extending between the two conducting layers. Then, the conventional via holes, as discussed in [13], will instead be metal pins or the like, which are manufactured as PGAs forming a PGA rectangular waveguide cavity or a PGA gap waveguide cavity between the two metal plates, within each unit cell of the whole antenna array.

[0075] In Fig 4, a top view of an example of the texture in the lower PCB of the antenna in Figure 3 is illustrated. This shows a distribution network 41 in ridge gap waveguide technology in accordance with [13], for waves in the gap between the two PCBs. The ridge structure forms a branched so-called corporate distribution network from one input port 42 to four output ports 43. The distribution network may be much larger than this with many more output ports to feed a larger array. In contrast to the antenna of [13], the via-holes arranged to provide a stopping texture are here formed as protruding elements 44 formed by PGA and/or BGA, to form a PGA gap waveguide. Hereby, there is no or partly no substrate and the via holes are replaced by the pins of the PGA. The ridge structure is drawn as a thin metal strip, a microstrip, supported by pins. However, it is also feasible to replace the strip 45 with a ridge formed in a separate manufacture process such as by spark erosion, and mount this ridge on the lower metal plate during the same procedure when the PGA is mounted. Thereby the ridge becomes a solid ridge such as shown in the ridge gap waveguides in e.g. [4].

[0076] With reference to Fig 5, another embodiment of an antenna will now be discussed. This antenna comprises three layers, illustrated separately in an exploded view. The upper layer 51 (left) comprises an array of radiating horn elements 52 formed therein. The middle layer 53 is arranged at a distance from the upper layer 51, so that a gap towards the upper layer is provided. This middle layer 53 comprises a microstrip distribution network 54 arranged on a substrate having no ground plane. The waves propagate in the air gap between the upper and middle layer, and above the microstrip paths. A lower layer 55 (right) is arranged beneath and in contact with the middle layer 53. This lower layer comprises an array of protruding elements 56, such as metal pins, manufactured using PGA and/or BGA technology, on a conducting layer 57. The conducting layer may be formed as a separate metal layer or as a metal surface of an upper ground plane of a PCB. The protruding elements are connected to the conducting layer in such a way that metal contact between the bases of all protruding elements is ensured.

[0077] Thus, this antenna functionally and structurally resembles the antenna disclosed in [12], said document hereby being incorporated in its entirety by reference. However, whereas this known antenna was realized by milling to form an inverted microstrip gap waveguide network, the present example provides a distribution network realized as a PGA inverted microstrip gap waveguide, which entails many advantages, as has been discussed thoroughly in the foregoing sections of this application.

[0078] Fig 6 provides a close-up view of an input port of a microstrip-ridge gap waveguide on a lower PCB showing a transition to a rectangular waveguide through a slot 63 in the ground plane. In this embodiment, there is no dielectric substrate present, and the conventionally used via holes are replaced by protruding PGA elements 61, connected to a conducting layer 62 in such a way that there is electric contact between all the protruding elements 61. Thus, a PGA microstrip gap waveguide is provided. The upper metal surface is removed for clarity. The microstrip supported by pins, i.e. the micrtostrip-ridge, may also be replaced by a solid ridge in the same way as discussed above in connection with Fig 4.

[0079] Fig 7 illustrates an exemplary embodiment of a gap waveguide filter, structurally and functionally similar to the one disclosed in [14], said document hereby being incorporated in its entirety by reference. However, contrary to the waveguide filter disclosed in this document, the protruding elements 71 arranged on a lower conducting layer 72 are here formed by PGA technology. An upper conducting layer 73 is arranged above the protruding elements, in the same way as disclosed in [12]. Thus, this then becomes a groove PGA gap waveguide filter.

[0080] Fig 8 provides another example of a waveguide filter, which may also be referred to as gap-waveguide-packaged microstrip filter. This filter functionally and structurally resembles the filter disclosed in [15], said document hereby being incorporated in its entirety by reference. However, contrary to the filter disclosed in [15], the filter here is packaged by a PGA surface, in which protruding elements 81 provided on a conducting layer 82 are realized as PGA. Two alternative lids, comprising different number and arrangement of the protruding elements 81 are illustrated.

[0081] With reference to Fig 9, an embodiment providing a package for integrated circuit(s) will be discussed. In this example, the integrated circuits are MMIC amplifier modules 91, arranged in a chain configuration on a lower plate 92, here realized as a PCB having an upper main substrate, provided with a lower ground plane 93. A lid is provided, formed by a conducting layer 95, e.g. made of aluminum or any other suitable metal. The lid may be connected to the lower plate 92 by means of a surrounding frame or the like.

[0082] The lid is further provided with protruding elements 96, 97, protruding towards the lower plate 92. This is functionally and structurally similar to the package disclosed in [16], said document hereby being incorporated in its entirety by reference. The protruding elements are preferably of different heights, so that the elements overlying the integrated circuits 91 are of a lower height, and the elements overlying areas laterally outside the integrated circuits are of a greater height. Hereby, holes are formed in the surface presented by the protruding elements, in which the integrated circuits are inserted. The protruding elements are in electric contact with the upper layer 95, and electrically connected to each other by this layer. However, the protruding elements are preferably not in contact neither with the lower plate 92, nor the integrated circuit modules 91.

[0083] Here, and contrary to the disclosure in [16], the protruding elements are formed on the upper layer 95 by PGA technology. This packaging is consequently an example of using the PGA gap waveguide as a packaging technology, according to the present invention.

[0084] The invention has now been described with reference to specific embodiments. However, several variations of the technology of the waveguide and RF packaging in the antenna system are feasible. For example, the here disclosed PGA and/or BGA realization of protruding elements can be used in many other antenna systems and apparatuses in which conventional gap waveguides have been used or could be contemplated. Further, even though PGA has been primarily discussed, it should be acknowledged that BGA may also be used in many of these embodiments.

[0085] Such and other obvious modifications must be considered to be within the scope of the present invention, as it is defined by the appended claims. It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting to the claim. The word "comprising" does not exclude the presence of other elements or steps than those listed in the claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. Further, a single unit may perform the functions of several means recited in the claims.

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[0086]

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Claims

1. A radio frequency (RF) part of an antenna system, e.g. for use in communication, radar or sensor applications, comprising at least two conducting layers arranged with a gap there between, and a set of periodically or quasi-periodically arranged protruding elements fixedly connected to at least one of said conducting layers, thereby forming a texture to stop wave propagation in a frequency band of operation in other directions than along intended waveguiding paths, wherein said protruding elements are formed as a pin grid array and/or a ball grid array, wherein each pin is fixed to the conducting layer by soldering, but wherein all protruding elements are connected electrically to each other at their bases via said conductive layer on which they are fixedly connected.

2. The RF part of claim 1, wherein the RF part is a waveguide, and wherein the protruding elements are further in contact with, and preferably fixedly connected to, also the other conducting layer, and wherein the protruding elements are arranged to at least partly surround a cavity between said conducting layers, said cavity thereby functioning as a waveguide.

3. The RF part of claim 1, wherein the RF part is a gap waveguide, and further comprising at least one groove, ridge or microstrip line along which waves are to propagate, and e.g. a microstrip line arranged as a suspended microstrip.

4. The RF part of any one of the preceding claims, wherein the protruding elements have maximum cross-sectional dimensions of less than half a wavelength in air at the operating frequency, and/or wherein the protruding elements in the texture stopping wave propagation are spaced apart by a spacing being smaller than half a wavelength in air at the operating frequency.

5. The RF part of any one of the preceding claims, further comprising a ball grid array arranged outside the protruding elements forming said texture to stop wave propagation, said ball grid array functioning as spacers between said conducting layers.

6. The RF part of any one of the preceding claims, wherein the protruding elements forming said texture to stop wave propagation are only in contact with one of the conducting layers.

7. The RF part of any one of the preceding claims, wherein at least one of the conducting layers is provided with at least one opening, preferably in the form of rectangular slot(s), said opening(s) allowing radiation to be transmitted to and/or received from said RF part.

8. The RF part of claim 7, wherein at least one of said slots is a coupling slot, which make a coupling from an end of a distribution network arranged in the textured surface to a continuation of this distribution network that divides the power equally into an array of additional slots that together form a radiating subarray of an array antenna, wherein the spacing between each slot of the subarray preferably is smaller than one wavelength.

9. The RF part of claim 8, wherein the RF part comprises two PCBs, wherein at least one first coupling slot is provided in a conducting layer separating the first and second PCB, and forming a radiating connection between a waveguide structure formed by the texture in the first PCB with a waveguide structure formed by the texture in the second PCB, and wherein an upper conducting layer of the second PCB is further provided with a plurality of radiating second openings, wherein the second PCB preferably forms a SIW cavity between the upper and lower conducting layers, said SIW cavity realizing a distribution network.

10. The RF part of any one of the claims 7-9, further comprising at least one corrugation between the subarrays in E-plane, realized by an elongated slot in the upper metal plate and pins on the form of metalized via holes or PGA along both sides of the slots.

11. The RF part of any one of the preceding claims, further comprising at least one integrated circuit module, such as a monolithic microwave integrated circuit module, arranged between said conducting layers, the texture to stop wave propagation thereby functioning as a means of removing resonances within the package for said integrated circuit module(s).

12. The RF part of claim 11, wherein the integrated circuit module(s) is arranged on a conducting layer not being provided with said protruding elements, and wherein protruding elements overlying the integrated circuit(s) are shorter than protruding elements not overlying said integrated circuit(s).

13. A flat array antenna comprising a corporate distribution network realized by an RF part in accordance with any one of the preceding claims.

14. A method for producing an RF part of an antenna system, e.g. for use in communication, radar or sensor applications, comprising:

providing a first conducting layer;
fixedly connecting a set of periodically or quasi-periodically arranged protruding elements to the first conducting layer, wherein said protruding elements are all electrically connected to each other via said conducting layer on which they are fixedly connected, and wherein said protruding elements are formed by pin grid array and/or ball grid array technology; and
providing a second conducting layer overlying said first conducting layer, so that a gap is formed there between;
wherein the protruding elements forms a texture to stop wave propagation in a frequency band of operation in other directions than along intended waveguiding paths within said gap.

15. The method of claim 14, wherein the step of providing protruding elements on the first conducting layer involves the steps of:

producing a pattern of the layout of the protruding elements and possible waveguide paths on the first conducting layer;
arranging the parts to be connected to the first conducting layer in a jig; and
connecting the parts to the first conducting layer.

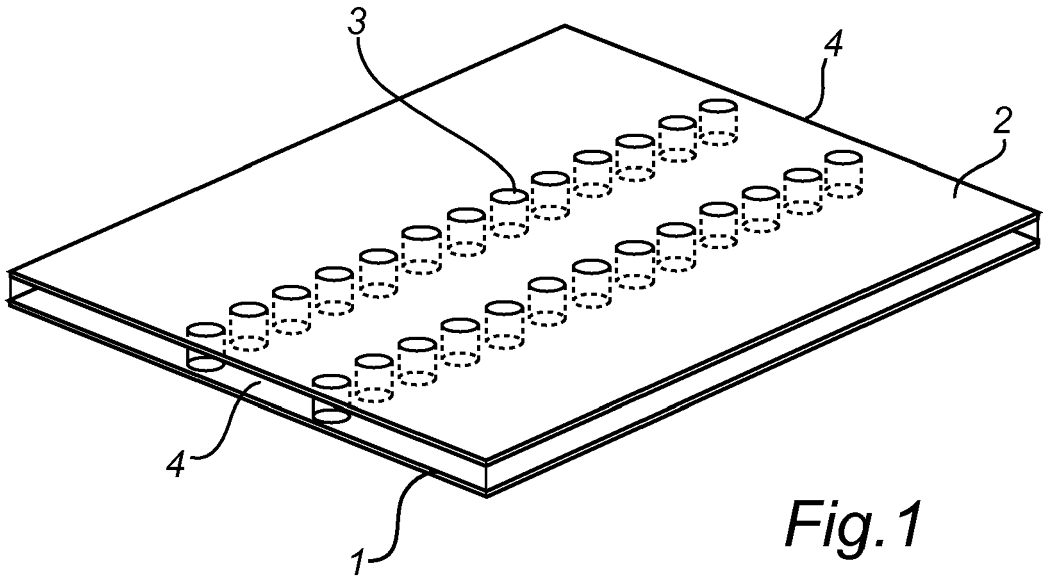

Fig.1

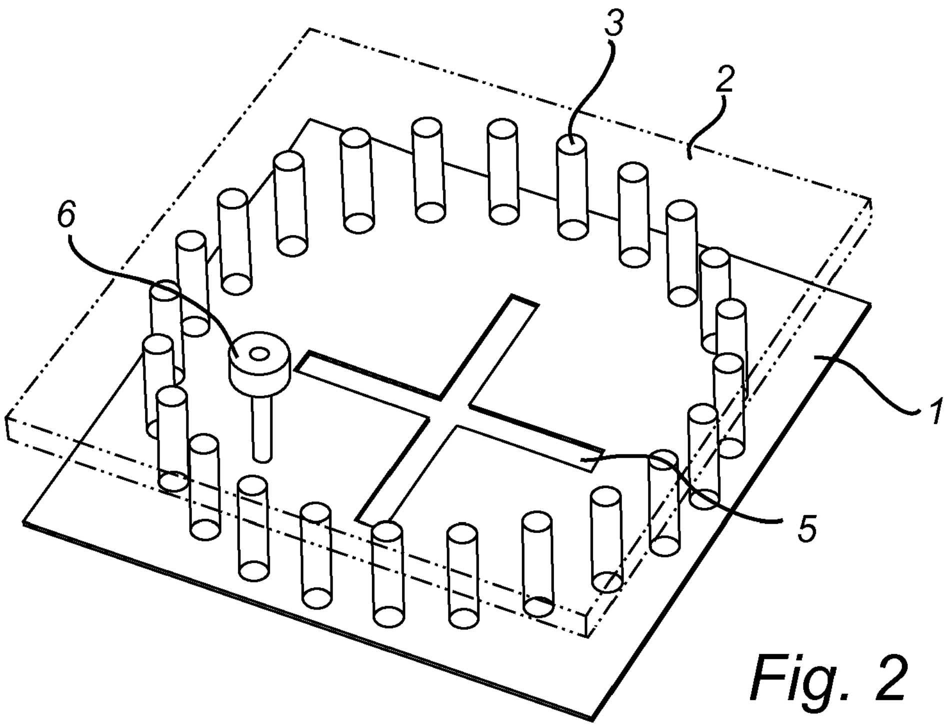

Fig. 2

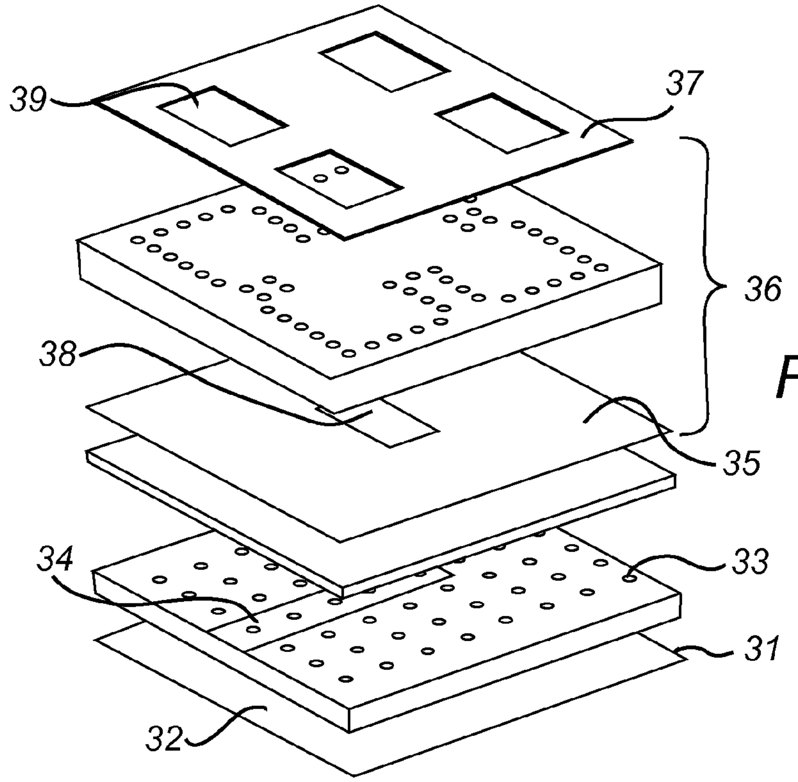

Fig.3a

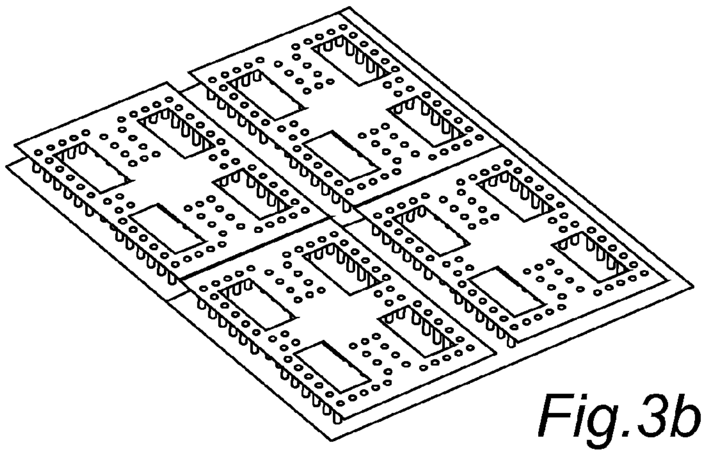

Fig.3b

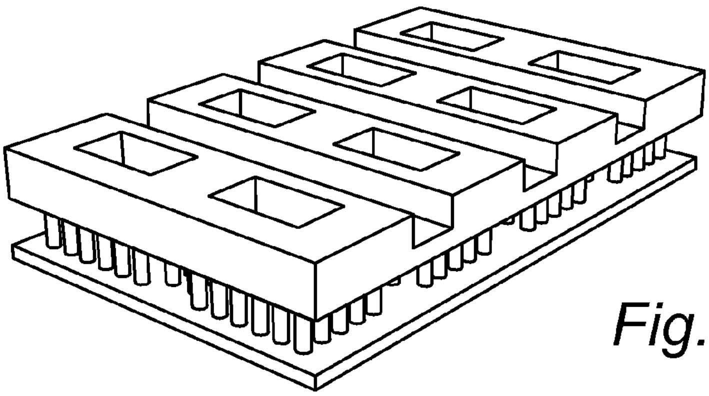

Fig.3c

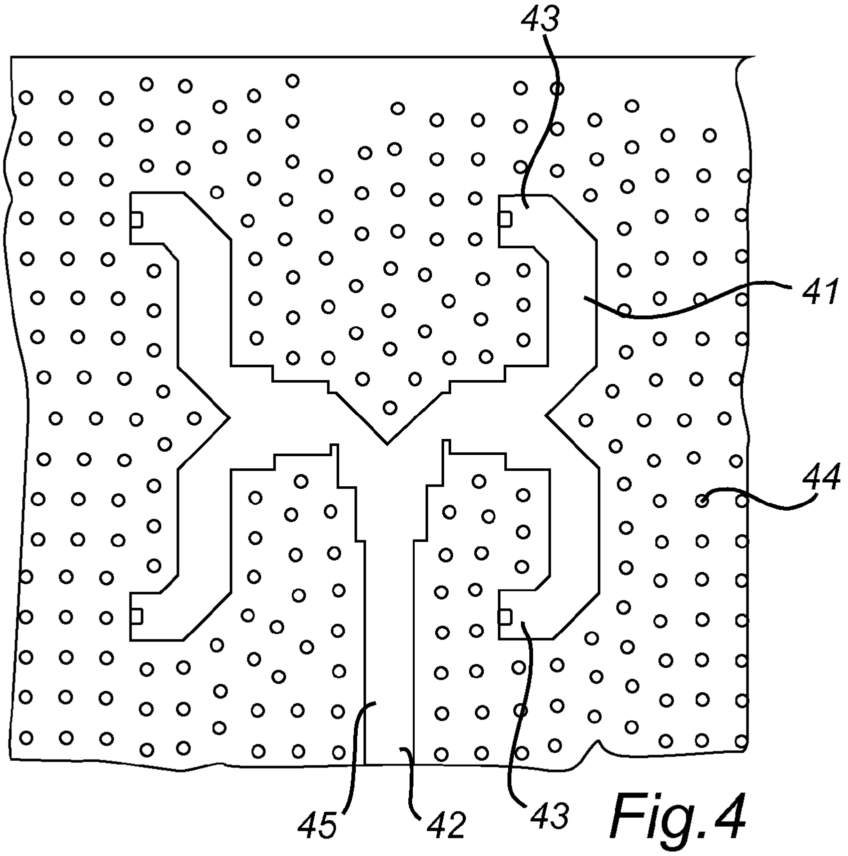

Fig.4

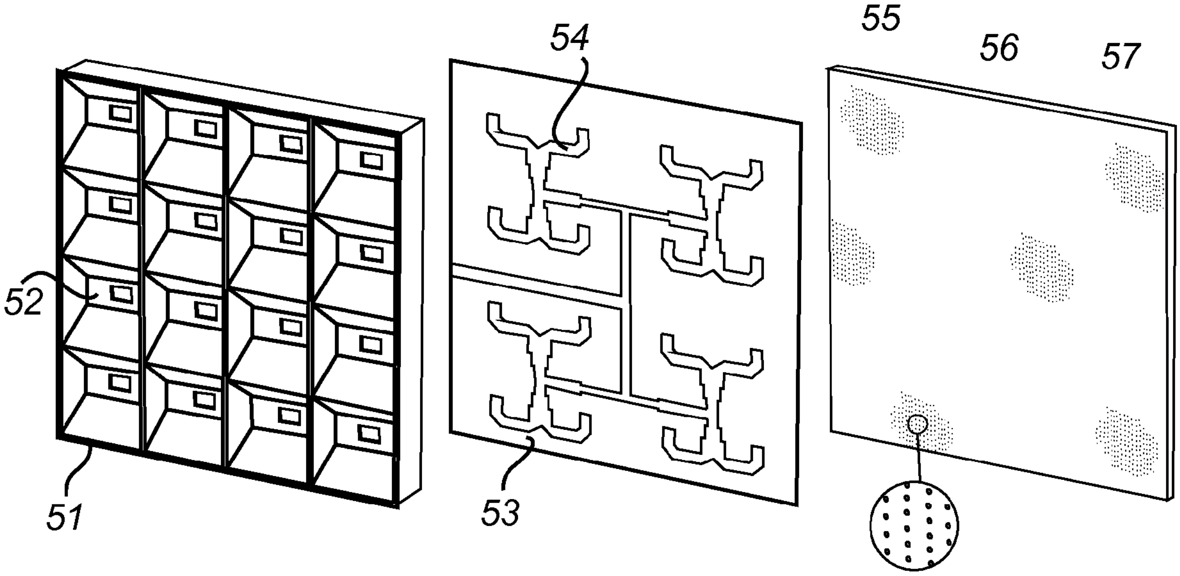

Fig.5

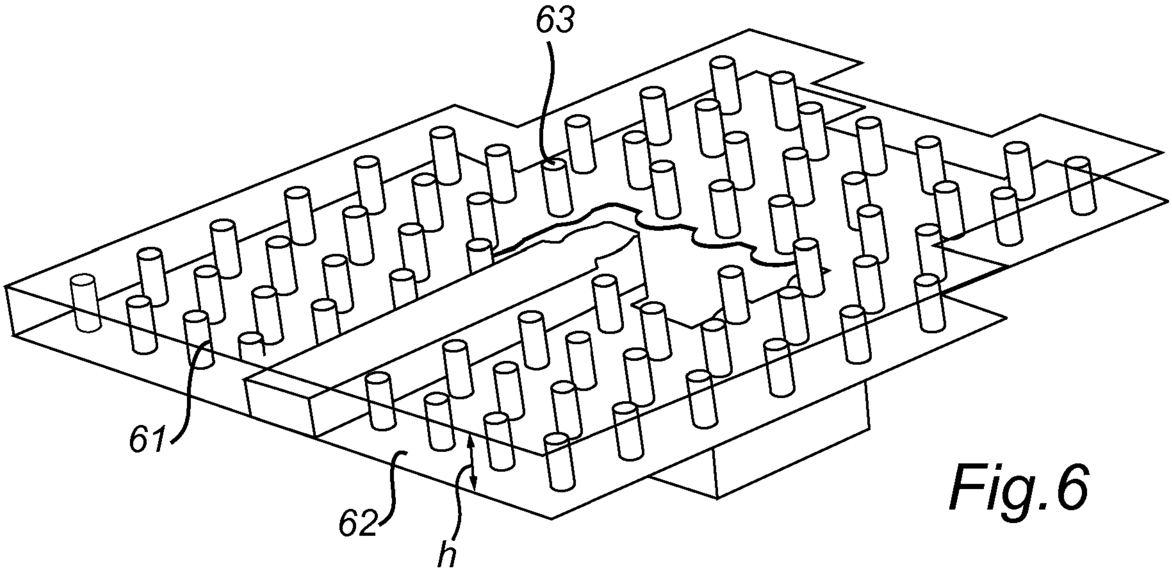

Fig.6

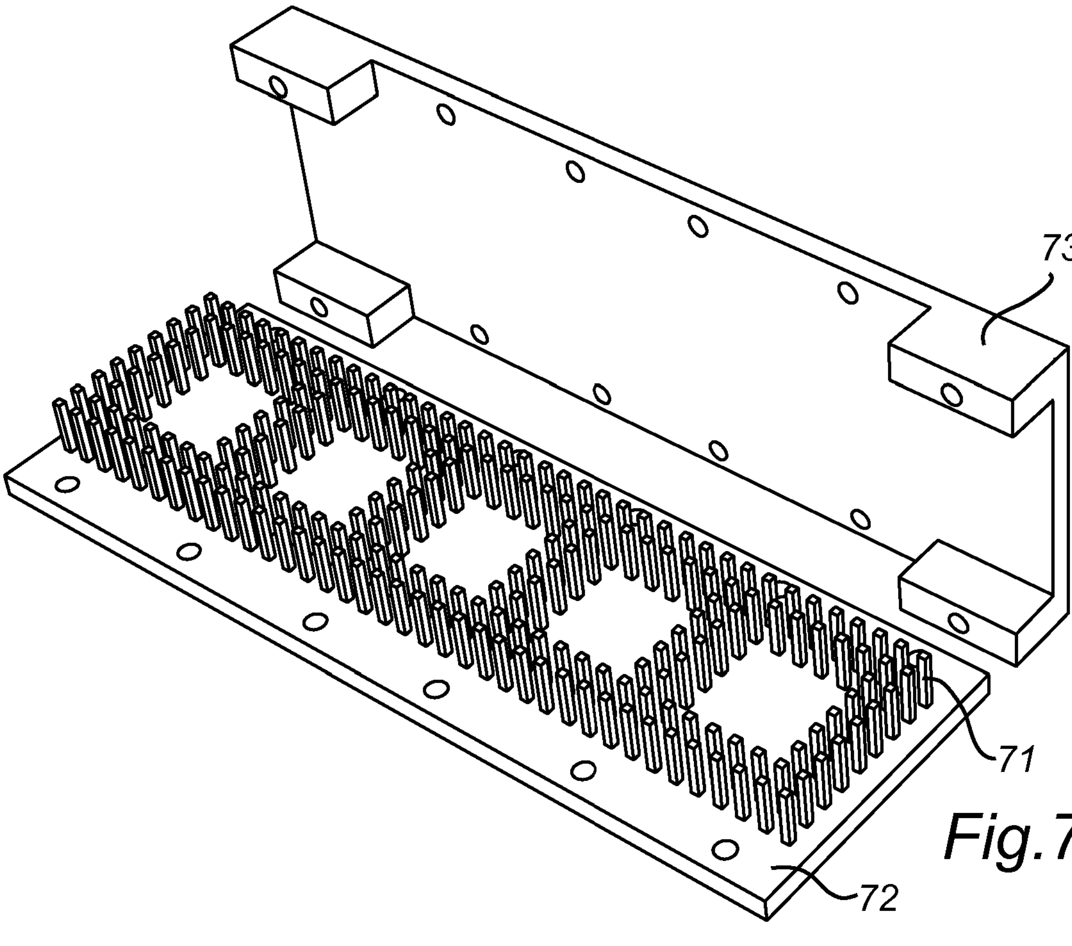

Fig.7

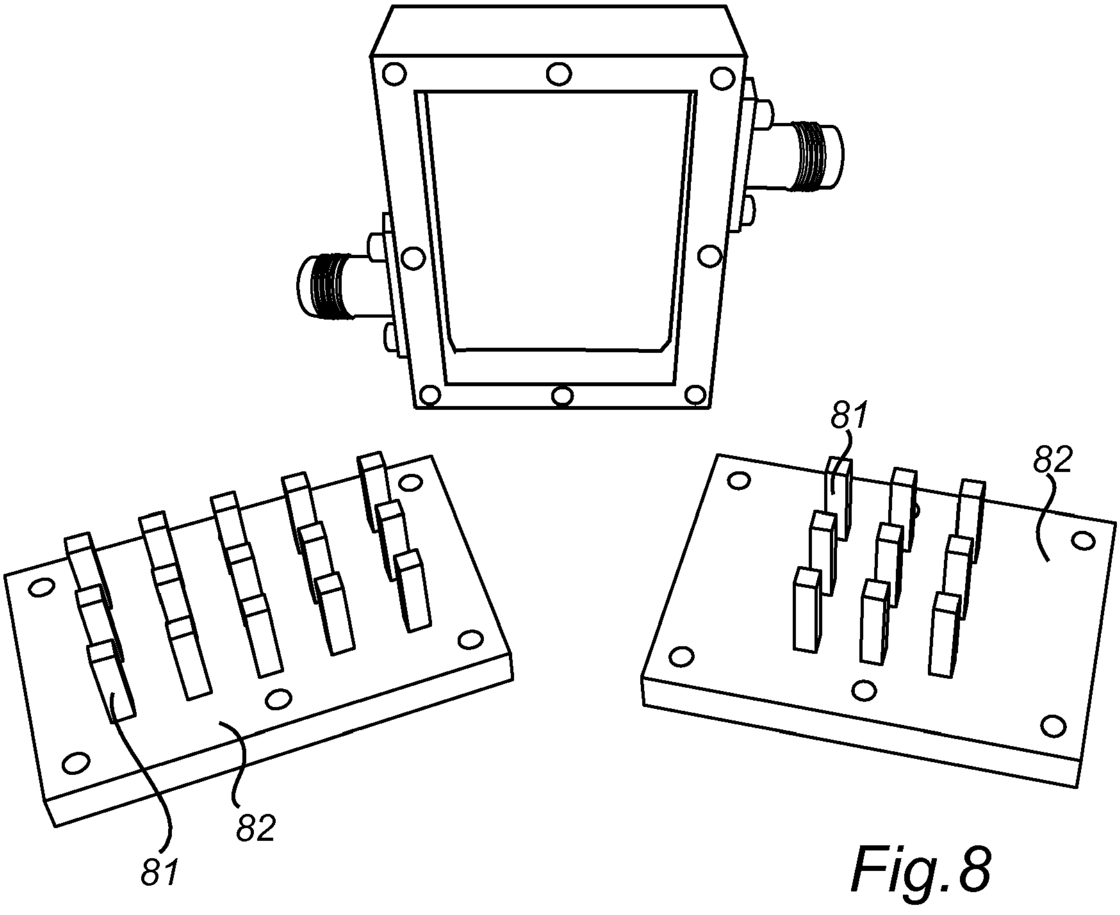

Fig.8

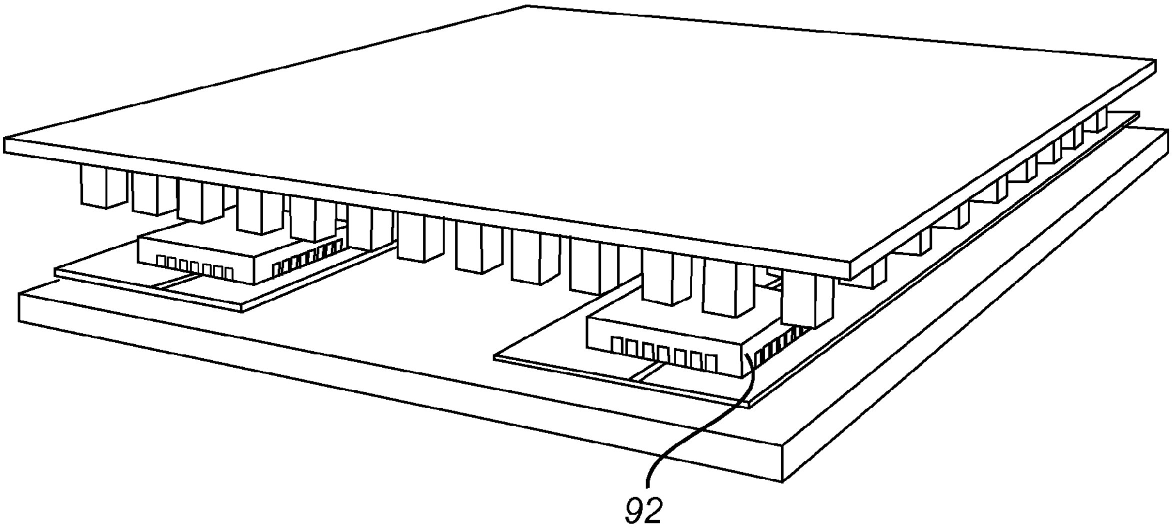

Fig. 9a

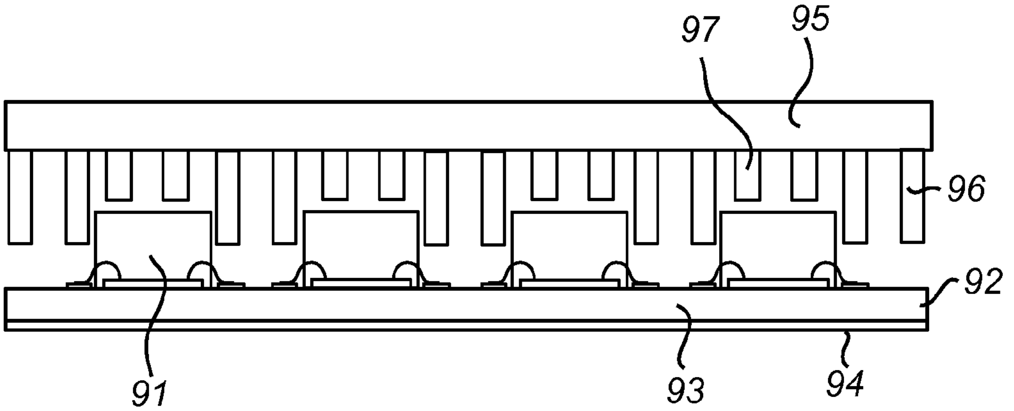

Fig. 9b

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EUROPEAN SEARCH REPORT

Application Number
EP 14 17 3128

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	US 2011/210431 A1 (LOISELET EMMANUEL [FR]) 1 September 2011 (2011-09-01) * paragraph [0025] - paragraph [0028]; figures 1-3 *	1,2,4,5, 14,15 3,6-13	INV. H01Q13/02 H01Q13/10 H01Q21/00 H01P11/00 H01P1/20 H01P3/123 H01P1/211
X A	US 6 194 669 B1 (BJORNDAHL WILLIAM D [US] ET AL) 27 February 2001 (2001-02-27) * column 3, line 35 - column 4, line 2; figures 1-3 * * column 5, line 29 - line 32 *	1,2,4,5, 14,15 3,6-13	
X	US 2011/285606 A1 (DE GRAAUW ANTONIUS JOHANNES MATHEUS [NL] ET AL) 24 November 2011 (2011-11-24) * paragraphs [0064], [0073]; figure 7 *	1,2,4,5, 7,14,15	
X A	EP 2 390 953 A1 (KILDAL ANTENN CONSULTING AB [SE]) 30 November 2011 (2011-11-30) * paragraph [0040] - paragraph [0049]; figures 1,2,4 *	1,3,4,6, 14,15 2,5,7-13	TECHNICAL FIELDS SEARCHED (IPC)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	23 September 2015	Sípal, Vít

CATEGORY OF CITED DOCUMENTS

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EUROPEAN SEARCH REPORT

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EUROPEAN SEARCH REPORT

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