(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 4 518 029 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
05.03.2025 Bulletin 2025/10

(21) Application number: **23197945.1**

(22) Date of filing: **18.09.2023**

(51) International Patent Classification (IPC):
H01Q 1/52 *(2006.01)* ***H01Q 15/00*** *(2006.01)*
H01Q 21/00 *(2006.01)* ***H01Q 21/06*** *(2006.01)*
H01Q 1/32 (2006.01)

(52) Cooperative Patent Classification (CPC):
H01Q 21/064; H01Q 1/523; H01Q 15/008; H01Q 21/0062; H01Q 1/3233

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

(30) Priority: **31.08.2023 EP 23194665**

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(54) **MICROWAVE DEVICE**

(57) A microwave device (100) comprising a first sheet (10) and a second sheet (20) spaced from the first sheet (10) with a gap (15) therebetween is provided. The second sheet (20) comprises a propagation structure (25) in which an electromagnetic wave (EM) having a maximum wavelength can propagate and configured to radiate the electromagnetic wave towards the first sheet (10);, a coupling structure (26) configured to establish an electromagnetic coupling of the propagation structure (25) to or from outside, and an electromagnetic band gap, EBG, structure (22) configured to suppress a propagation of the electromagnetic wave across the second sheet (20). Either the first sheet (10) or the second sheet (20) comprises an antenna structure (40-1, 40-2) for emitting and/or receiving the electromagnetic wave to/from the environment.

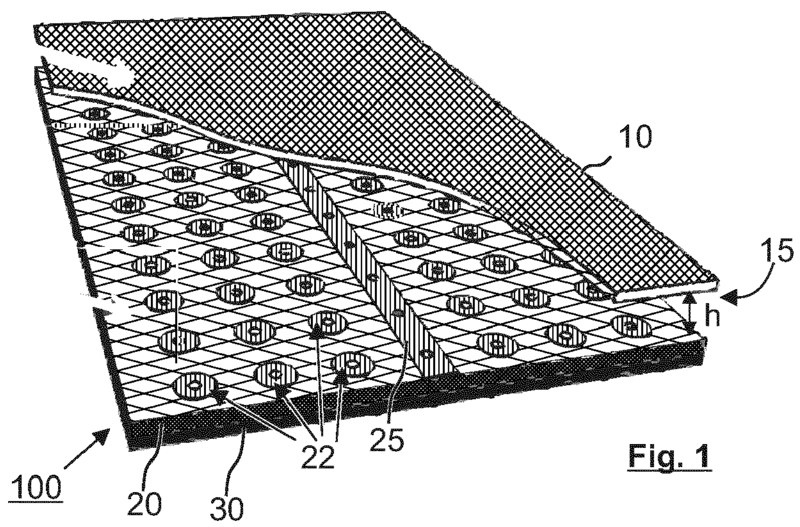

Fig. 1

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Description

TECHNICAL FIELD

[0001] Embodiments of the present disclosure generally relate to microwave devices.

BACKGROUND

[0002] Microwave devices are used in a variety of technical fields. For example, automotive radar systems employ microwave devices for generation and/or reception of electromagnetic waves (radar waves) to collect data on the environmental situation even when operating in poor weather conditions and harsh environments, the data including velocity information, high resolution information for distances and angles. For example, a radar operating on 77 GHz uses such a microwave device, but frequencies above 100 GHz are conceivable as well.

[0003] In microwave devices, it is desired to transfer a high frequency (HF) signal, or radio frequency (RF) signal, from the microwave device to a radiation element, or antenna structure, with low loss. Conventional microwave devices are known that use printed radiation elements and transmission lines on a printed circuit board (PCB), such as patch antennas and microstrip or slotted surface-integrated waveguides. Such conventional microwave devices generally have a high dielectric loss. Some other conventional microwave devices use air waveguide and gap waves structures. Those conventional devices suffer from back-shorts and milled metallic parts that need high accuracy in alignment. Some other conventional devices use multilayer waveguides in which air-filled waveguides are realized by stacking together multiple unconnected layers.

[0004] There is a demand for a low-cost microwave device having a simple and effective configuration.

SUMMARY OF THE DISCLOSURE

[0005] A microwave device is provided. The microwave device comprises a first sheet and a second sheet. The second sheet is spaced from the first sheet with a gap between the first and the second sheet. The second sheet comprises a propagation structure and a coupling structure with active components. The propagation structure is configured such that an electromagnetic wave can propagate in the propagation structure. The electromagnetic wave has a certain wavelength defined by its frequency. Typically, the proportions of the propagation structure define a maximum wavelength of the electromagnetic wave that can propagate within the propagation structure. The propagation structure is further configured such that the electromagnetic wave is radiated towards the first sheet. In the case of the electromagnetic wave coming from the direction of the first sheet, the propagation structure allows for a reception of the electromagnetic wave. The coupling structure is configured to establish an electromagnetic coupling of the propagation structure to or from the outside. The microwave device further comprises an electromagnetic band gap structure (EBG structure). The EBG structure is configured to suppress a propagation of the electromagnetic wave across the second sheet and/or beyond the first sheet. Either the first sheet or the second sheet comprises an antenna structure for emitting and/or receiving the electromagnetic wave to/from the environment.

[0006] Spaced from one another, as used herein, is an arrangement of the involved parts at a distance.

[0007] A sheet, as used herein, includes any planar material extending essentially in a plane and typically having only a minute extension in the direction orthogonal to the plane, such as a board or a plate, and in/on which the elements stated herein can be placed or integrated. For example, any one of the first or second sheet may be a circuit board, such as a multilayers printed circuit board (PCB).

[0008] The gap, as used herein, is typically filled with air at ambient pressure. However, there is no particular limitation to this, and devices are conceivable in which the space in the gap is filled with air at a pressure different from the ambient pressure, or includes a gas different from air, or includes air plus a gas different from air.

[0009] The EBG structure may have a bandgap in the operating frequency, e.g. a frequency at or below the maximum frequency of the electromagnetic wave, to block the propagation of the RF signal in undesired directions. In an embodiment, the EBG structure is at least partially provided at (e.g., on or in) the second sheet. The EBG structure at the second sheet is configured such that it suppresses a propagation of the electromagnetic wave away from the propagation structure. Away from the propagation structure may designate any direction that is not on a substantially direct path between the propagation structure and the first sheet, e.g. a direction across the second sheet (i.e., abeam to the desired propagation direction of the electromagnetic wave in the gap). In an embodiment, the EBG structure is at least partially provided at (e.g., on or in) the first sheet. The EBG structure at the first sheet is configured such that it suppresses a propagation of the electromagnetic wave beyond the first sheet. The EBG may be regarded as an artificial magnetic conductor, AMC. Thanks to the AMC, the electromagnetic wave propagates in the air gap with substantially no dielectric losses.

[0010] The wavelength is not particularly limited, but is typically in the microwave range, and preferably corresponds to a frequency above 10 GHz and below 200 GHz. A typical, non-limiting example of a wavelength range for the wavelength corresponds to a radar frequency band of e.g. 76-81 GHz.

[0011] In embodiments, the first sheet is composed of a material that is electromagnetically reflective for the electromagnetic wave at the desired wavelength, e.g. up to the desired wavelength. In particular, the first sheet is composed of metal material. For example, the first sheet consists substantially entirely of the metal material.

[0012] An EBG structure, as used herein, may be a structure essentially complying with the disclosure set forth in patent document DE 10 2006 012 452 B4, which is incorporated herein by reference in its entirety. This applies to the EBG structure present in the second sheet as well as an EBG structure possibly present in the first sheet. An EBG structure, or PBG structure, may have a periodicity giving it a frequency selective (i.e., filtering) property. For example, an EBG structure may include a (periodic) line-up of conductive elements that are arranged above an electrical reference potential surface. Other examples include strip elements that are periodically arranged above an electrical reference potential surface, in one direction in a plane parallel to the surface. Thanks to the EBG, an electromagnetic wave having a wavelength in a wavelength range complying with the geometrical properties of the EBG structure is thus essentially blocked from propagating along the EBG structure. The EBG structure may achieve a broadband stopband characteristic.

[0013] In embodiments, the antenna structure is formed in the second sheet. The electromagnetic wave may first propagate towards the first sheet to be at least partially reflected at the first sheet, and then propagate back towards the second sheet in which the antenna structure is formed, to be radiated from the antenna structure. In this way, there is no need to guide the electromagnetic wave to the antenna structure, e.g. via a strip line, which may require a special material of the second sheet. In some embodiments, the antenna structure may include one or more slots, i.e. a slot-type antenna or slot array. In some embodiments, an EBG structure may be present in between the slots of the slot array, in particular between more than half of the slots of the slot array and preferably between substantially all of the slots of the slot array. The EBG structure may help to reduce an undesired coupling between multiple antennas.

[0014] In embodiments, the distance between a surface of the first sheet that is opposed to the second sheet and a surface of the second sheet that is opposed to the first sheet is less than a quarter of the wavelength, e.g. the design wavelength and/or the maximum wavelength. In this way, the propagation of the electromagnetic wave is not affected by the length of the gap; in particular, resonant effects within the gap are suppressed.

[0015] In embodiments, the second sheet is a printed circuit board, PCB. In particular, in some embodiments, the material of the PCB is a non-RF material. As a RF material is not needed because the electromagnetic wave mainly propagates in air, this may contribute to a low-cost, yet effective solution. The non-RF material may include a PCB material selected from the group consisting of FR2, FR3, CEM1, CEM3, FR4, FR5. In embodiments, the non-RF material is FR4.

[0016] In embodiments, the propagation structure includes an essentially continuous ridge. In particular, the ridge may extend essentially continuously from an edge region of the second sheet to an opposite edge region of the second sheet. In some embodiments, the propagation structure includes a waveguide, in particular an air-waveguide.

[0017] In embodiments, the coupling structure includes a waveguide. An example of a waveguide is, without limitation, a WR10 waveguide.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Embodiments of the present disclosure are described below in more detail while referring to the drawings in which:

Fig. 1 illustrates a partial perspective view of a microwave device according to an embodiment;

Fig. 2 illustrates a side sectional view of the device of Fig. 1;

Fig. 3 illustrates a schematic exaggerated sectional side view of the device of Fig. 1 with radiated slots;

Fig. 4 illustrates a schematic exaggerated sectional side view of a microwave device according to another embodiment;

Fig. 5 illustrates a schematic exaggerated sectional side view of the device of Fig. 4, at another location where radiation slots are present.

Fig. 6 illustrates a schematic exaggerated sectional side view of a microwave device according to yet another embodiment;

Fig. 7 illustrates a schematic exaggerated sectional side view of the device of Fig. 6, at another location where radiation slots are present;

Fig. 8 illustrates a schematic exaggerated sectional side view of an array of microwave devices according to yet another embodiment.

DETAILED DESCRIPTION

[0019] Technology is described hereinafter with reference to the figures, in which aspects exemplary embodiments are shown.

[0020] The claimed invention may, however, be embodied in different forms and should not be construed as being limited to the embodiments set forth herein. Like reference numerals refer to like elements throughout. Like elements will, thus, not be described in detail with respect to the description of each figure. It should also be noted that the figures are only intended to facilitate the description of the embodiments. They are not intended as an exhaustive description of the claimed invention or as a limitation on the scope of the claimed invention. In addition, an illustrated embodiment needs not have all the aspects or advantages shown. An aspect or an advantage described in conjunction with a particular embodiment aspect is not necessarily limited to that embodiment aspect and can be practiced in any other embodiments aspects even if not so illustrated, or if not so explicitly described. The features, functions, and advantages may be achieved independently in various embodiments manners or may be combined in yet other embodiments.

[0021] Before describing exemplary embodiments aspects illustratively depicted in the several figures, a general introduction is provided to further understanding. Radar systems, such as those used in automotive applications, often employ microwave devices that are at least partially implemented on a printed circuit board, PCB. Radio frequency (RF)/high frequency (HF)-capable PCB board materials exhibit superior behavior regarding low losses but are expensive. A widespread, cheap PCB material used for non-HF applications is, without limitation, FR4, which, however, exhibits a high-loss behavior for HF applications, e.g. strip lines etc. Printed radiating elements and transmission lines on PCBs such as microstrip lines suffer from dielectric loss. When air waveguides are used in conjunction with PCBs, there is often a need for obeying very tight mechanical tolerances in fabrication and in the alignment during the assembly. With the above general understanding borne in mind, embodiments for microwave devices are described below.

[0022] Fig. 1 illustrates a partial perspective view of a microwave device 100 according to an embodiment. Fig. 2 illustrates the microwave device 100 of Fig. 1 in a sectional side view. Fig. 3 illustrates the microwave device 100 of Figs. 1 and 2 in a sectional side view in which the dimensions orthogonal to the main extension plane of the microwave device 100 are exaggerated for the ease of understanding. For convenience, the following description commonly refers to Figs. 1-3 without making a particular distinction therebetween.

[0023] The device 100 includes a first sheet 10 and a second sheet 20. The second sheet 20 is arranged substantially parallel to the first sheet 10, and a gap 15 having a substantially same height h is formed between the first sheet 10 and the second sheet 20. The sheets are both planar bodies extending essentially in a plane. They have generally small thicknesses orthogonal to the extending directions of the plane. The second sheet 20 is a circuit board, or printed circuit board, PCB, of a non-RF/RF material. Non-limiting examples include an FR4 non-RF material. On a lower surface of the second sheet 20, a metallic surface 30 is present. The metallic surface 30 serves as a ground plane. Extending from the metallic surface 30 are elements 22-1, 22-2, 22-3 of an electromagnetic band gap structure 22 ("electromagnetic band gap" may be abbreviated as "EBG" herein). For convenience, only three of the EBG elements 22-1, 22-2, 22-3 are particularly labelled with a reference numeral; yet, it is understood that typically, more than three EBG elements are present. Neighboring EBG elements have a periodicity corresponding to a desired RF blocking. The EBG structure 11 has a frequency selective property. As shown in Figs. 1-3, the EBG structure 11 includes a periodic line-up of the conductive EBG elements 22-1, 22-2, 22-3... An electromagnetic wave having a wavelength in a wavelength range complying with the geometrical properties of the EBG structure (e.g., the elongation/thickness of the EBG elements, their pitch etc.) is thus essentially blocked from propagating along the EBG structure and thus outside the second sheet 20. The height h of the gap 15 is chosen to allow propagation between top of the second sheet 20 and bottom of the first sheet (10) at the wavelength that the microwave device 100 is designed for, e.g. a design wavelength.

[0024] Throughout the figures, the blockage of an undesired coupling from the microwave device 100 to the environment, e.g. to the outside, is indicated by dotted-line arrows crossed by an X.

[0025] A propagation structure 25 in the form of a ridge that extends substantially continuously from one edge of the second sheet 20 to the opposite edge of the second sheet 20 (in the drawing: from the edge located nearest to the viewer to the edge located farthest from the viewer). The propagation structure can also be a waveguide. A coupling structure 26, e.g. a waveguide, allows for an electromagnetic coupling from the outside to the propagation structure 25 and vice-versa. It is noted that "outside" in this context generally includes an interface that transfers an electromagnetic (EM) wave from an external device (i.e MMIC, line-based feed) to the propagation structure (25) and usually no wireless propagation from and to free space, as opposed to the antenna structure described further below.

[0026] In the propagation structure 25, an electromagnetic (EM) wave propagates. The propagation structure 25 is configured to radiate the electromagnetic wave EM in the direction of the first sheet 10. It is understood that while the propagation direction from the propagation structure towards the first sheet 10 is used here as an example, the device 100 also works for the opposite direction.

[0027] In the embodiment shown in Figs. 1-3, the first sheet 10 is metallic. It reflects a wave incident from the propagation structure back to the second sheet 20. Furthermore, in the embodiment shown in Figs. 1-3, the second sheet 20 additionally includes antenna slots 40-1, 40-2 forming an antenna structure. The electromagnetic wave EM reflected from the first sheet 10 and now incident on the antenna slots 40-1, 40-2 can propagate to be radiated from the antenna slots 40-1, 40-2. The EBG structure 22 in the second sheet 20 suppresses a propagation of the electromagnetic wave EM across the second sheet 20, i.e. in a direction deviating from the through direction of the antenna slots 40-1, 40-2.

[0028] Fig. 4 illustrates a schematic exaggerated sectional side view of a microwave device 100 according to another embodiment. Only the differences to the microwave device 100 in the embodiment of Figs. 1-3 are described here. In Fig. 4, the microwave device 100 includes, as the first sheet 10, a multilayers PCB. In/on the first sheet 10, transmission lines 13 are provided that make use of the electromagnetic wave EM incident on the first sheet 10. In Fig. 4, the EBG structure 22 is provided in the second sheet 20, i.e. an inner layer of the second sheet 20 facing an inner layer of the first sheet 10 by the gap 15. However, the EBG structure 22 may also be provided in the inner layer of the first sheet 10 facing the inner layer of the second sheet. In each case, an undesired coupling from the microwave device 100 to the environment, e.g. to the outside, is efficiently blocked by the use of the EBG structure 22.

[0029] Fig. 5 illustrates a schematic exaggerated sectional side view of a microwave device 100 according to yet another embodiment. The microwave device 100 of Fig. 5 is configured similarly to that of Fig. 4, and only the differences are described here. As in Fig. 4, the microwave device shown in Fig. 5, the microwave device 100 includes, as the first sheet 10, a multilayer PCB. An EBG structure 22-i is provided on an inner layer of the second sheet 20 facing an inner layer of the first sheet 10. Another EBG structure 22-o is implemented on an outer layer of the second sheet 20. The electromagnetic wave EM confined on the transmission structure thanks to the EBG structure 22-i and now incident on the antenna slots 40-1, 40-2 can propagate to be radiated from the antenna slots 40-1, 40-2. The EBG structure 22-o on the outer layer of the second sheet 20, i. e. implemented in the external layers of the multilayer PCB in the second sheet 20, suppresses a propagation of the electromagnetic wave EM across the slot array reducing the coupling of next slot column.

[0030] Fig. 6 illustrates a schematic exaggerated sectional side view of a microwave device 100 according to yet another embodiment. The microwave device 100 of Fig. 6 is configured similarly to that of Fig. 4, and only the differences are described here. As in Fig. 4, the microwave device shown in Fig. 6, the microwave device 100 includes, as the first sheet 10, a multilayer PCB. Instead of a ridge, the propagation structure 25 in the embodiment shown in Fig. 6 is formed as an air-waveguide delimited, in the gap 15, by side walls 16. The electromagnetic wave EM is radiated from the propagation structure 25, i.e. the waveguide, towards the first sheet 10.

[0031] Fig. 7 illustrates a schematic exaggerated sectional side view of a microwave device 100 according to yet another embodiment. The microwave device 100 of Fig. 6 is configured similarly to that of Fig. 6, and only the differences are described here. The electromagnetic wave EM can propagate inside the waveguide implemented between first sheet 10 and second sheet to be radiated from the antenna slots 40-1, 40-2. An EBG structure 22-o, implemented in the external layers of the multilayer PCB in the second sheet 20, suppresses a propagation of the electromagnetic wave EM across the slot array reducing the coupling of next slot column, in a manner similar to that described in connection with the EBG structure 22-o of Fig. 5.

[0032] Fig. 8 illustrates a schematic exaggerated sectional side view of an array, or stack, of microwave devices 100-1, 100-2, 100-3. Each microwave device 100-1, 100-2, 100-3 includes a propagation structure 25-1, 25-2, 25-3, in the present example a ridge (25-1, 25-2, 25-3). It is noted that one or more of the propagation structures 25-1, 25-2, 25-3 can also include a waveguide. EBG structures 22-1 through 22-8 are provided on an inner layer of the second sheet 20 facing an inner layer of the first sheet 10. Furthermore, corresponding EBG structures commonly referred to as EBG structures 22-o are provided on an outer layer (i.e. an external surface) of the second sheet 20. The EBG structures 22-1 through 22-8 on inner layer, or internal side, of second sheet 20 prevent an undesired coupling between the neighboring microwave devices 100-1, 100-2, 100-3 across the sheets 10, 20, as indicated by dotted-line arrows X in the Figure. The EBG structures 22-o on the external side of second sheet 20 prevent an undesired coupling between the slot antennas and improve the radiation pattern.

[0033] The microwave devices 100 described herein can be implemented using non-RF material. The number of layers used for the sheets, in particular the second sheet 20, is not particularly limited because the propagation of the electromagnetic wave occurs in air. Thus, the losses are suppressed, and the use of a standard PCB material such as FR4 will not have an impact on propagation losses. The transition between the propagation structure and the antenna occurs in the ridge air gap or in an air waveguide with low losses. In the PCB with the slots for the antenna structure, an additional EBG structure may be implemented to reduce the coupling between multiple antennas and to prevent ripples in the radiation pattern.

[0034] Although particular embodiments have been shown and described, it will be understood that it is not intended to limit the claimed inventions to the preferred embodiments, and it will be obvious to those skilled in the art that various changes and modifications may be made without department from the spirit and scope of the claimed inventions. The specification and drawings are, accordingly, to be regarded in an illustrative rather than restrictive sense. The claimed inventions are intended to cover alternatives, modifications, and equivalents.

Claims

1. A microwave device (100) comprising a first sheet (10) and a second sheet (20) spaced from the first sheet (10) with a gap (15) therebetween, the second

sheet (20) comprising:

- a propagation structure (25) in which an electromagnetic wave (EM) having a maximum wavelength can propagate and configured to radiate the electromagnetic wave towards the first sheet (10) and/or receive the electromagnetic wave coming from the direction of the first sheet (10);
- a coupling structure (26) configured to establish an electromagnetic coupling of the propagation structure (25) to or from outside;

wherein either the first sheet (10) or the second sheet (20) comprises an antenna structure (40-1, 40-2) for emitting and/or receiving the electromagnetic wave to/from the environment, wherein the microwave device (100) further comprises an electromagnetic band gap, EBG, structure (22) configured to suppress a propagation of the electromagnetic wave across the second sheet (20) and/or beyond the first sheet.

2. The microwave device (100) of claim 1, wherein the second sheet (10) comprises at least a part of the EBG structure (22) configured to suppress the propagation of the electromagnetic wave across the second sheet (20).

3. The microwave device (100) of claim 1 or 2, wherein the first sheet (10) comprises at least a part of the EBG structure configured to suppress the propagation of the electromagnetic wave beyond the first sheet (10).

4. The microwave device (100) of any one of the preceding claims, wherein the first sheet (10) is composed of an electromagnetically reflective material such as a metal material.

5. The microwave device (100) of any one of the preceding claims, wherein the antenna structure (40-1, 40-2) is formed in the second sheet (20).

6. The microwave device (100) of any one of the preceding claims, wherein a distance (h) between a surface of the first sheet (10) and a surface of the second sheet (20), as defined by the gap (15), is less than a quarter of the maximum wavelength.

7. The microwave device (100) of any one of the preceding claims, wherein the second sheet (20) is a printed circuit board, PCB.

8. The microwave device (100) of claim 7, wherein the material of the PCB is a non-RF material, in particular a PCB material selected from the group consisting of FR2, FR3, CEM1, CEM3, FR4, FR5, and preferably an FR4 material.

9. The microwave device (100) of any one of the preceding claims, wherein the propagation structure (25) includes an essentially continuous ridge, in particular a ridge extending essentially continuously from an edge region of the second sheet (20) to an opposite edge region of the second sheet (20).

10. The microwave device (100) of any one of the preceding claims, wherein the coupling structure (26) includes a waveguide, particularly a WR10 waveguide.

11. The microwave device (100) of any one of the preceding claims, wherein the propagation structure (25) includes an air-waveguide.

12. The microwave device (100) of any one of the preceding claims, wherein the antenna structure (40-1, 40-2) includes a slot array.

13. The microwave device (100) of claim 12, wherein an electromagnetic band gap, EBG, structure is present in between the slots of the slot array.

14. The microwave device (100) of any one of the preceding claims, wherein the maximum wavelength corresponds to a frequency of above 10 GHz.

15. The microwave device (100) of any one of the preceding claims, wherein the maximum wavelength corresponds to a frequency of below 200 GHz.

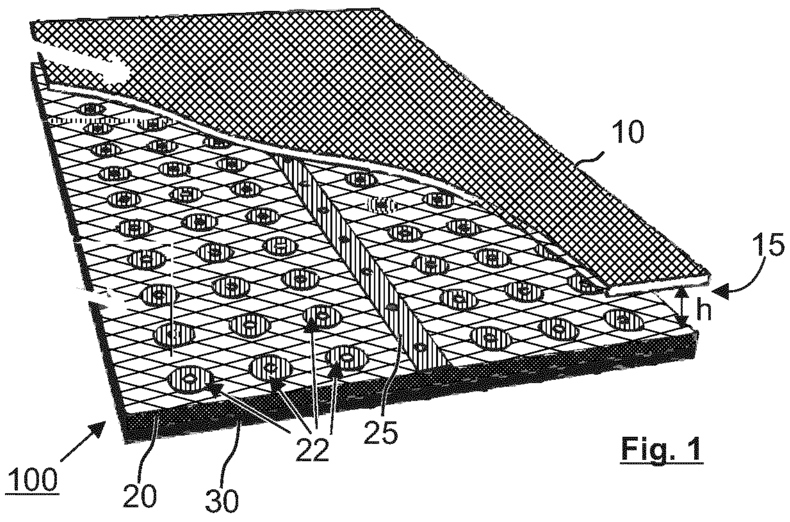

Fig. 1

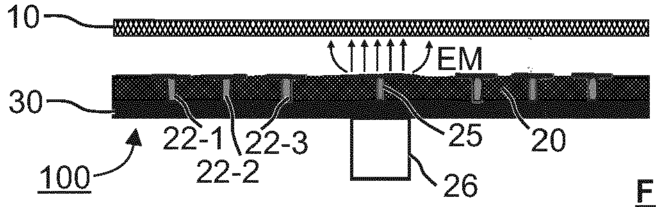

Fig. 2

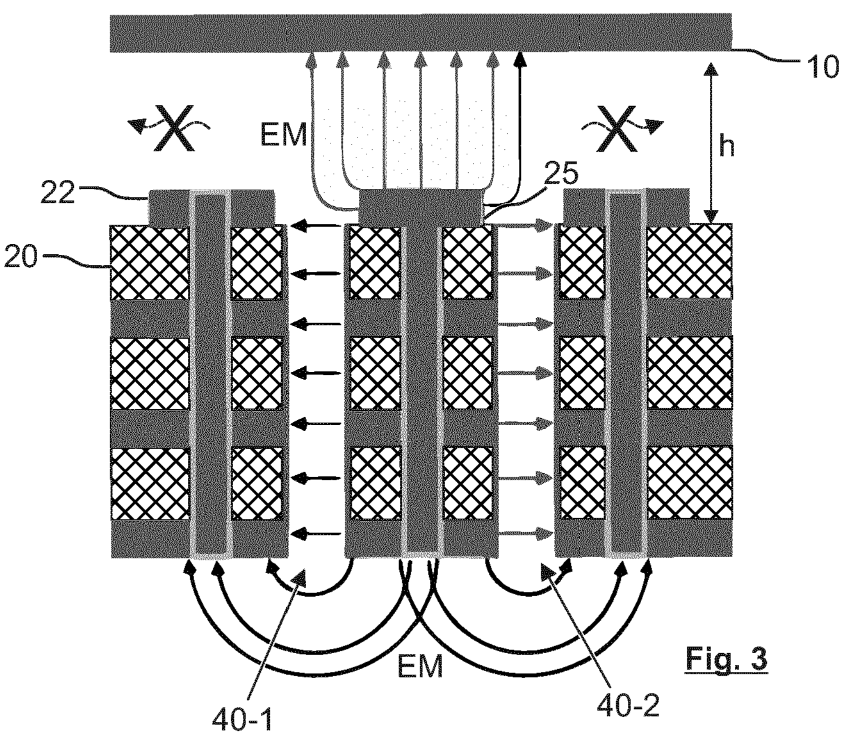

Fig. 3

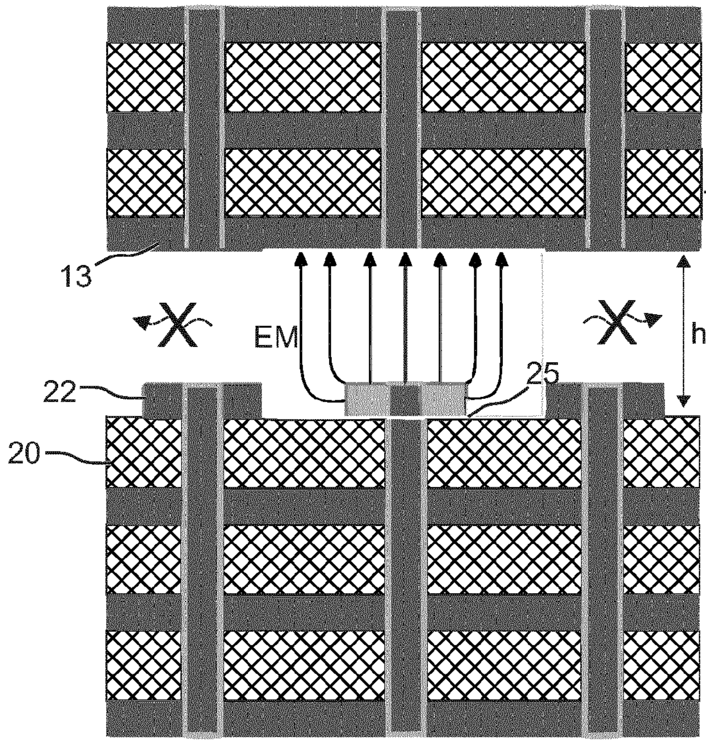

Fig. 4

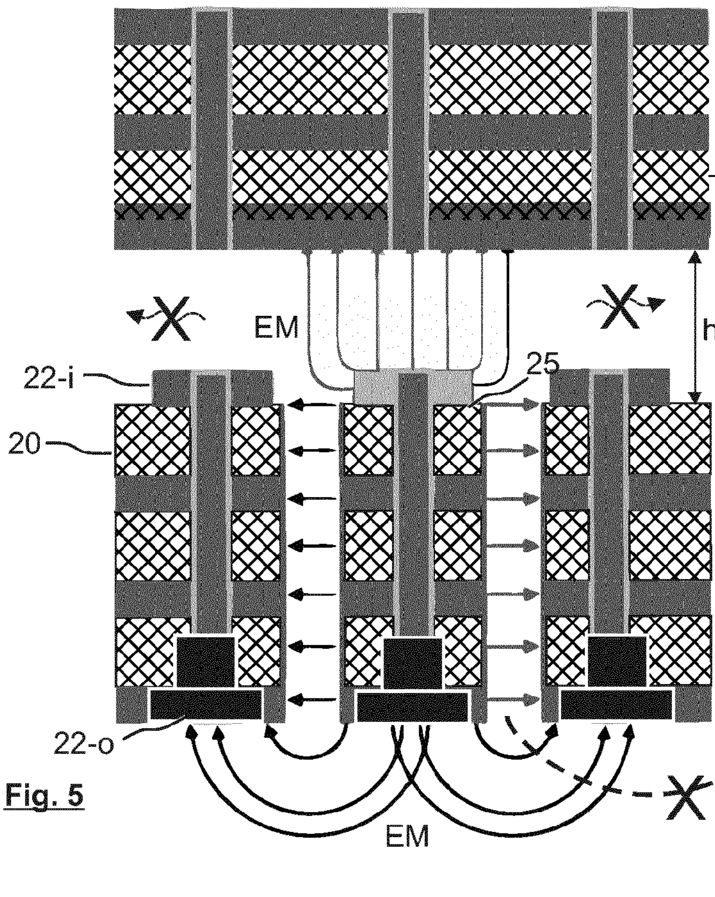

Fig. 5

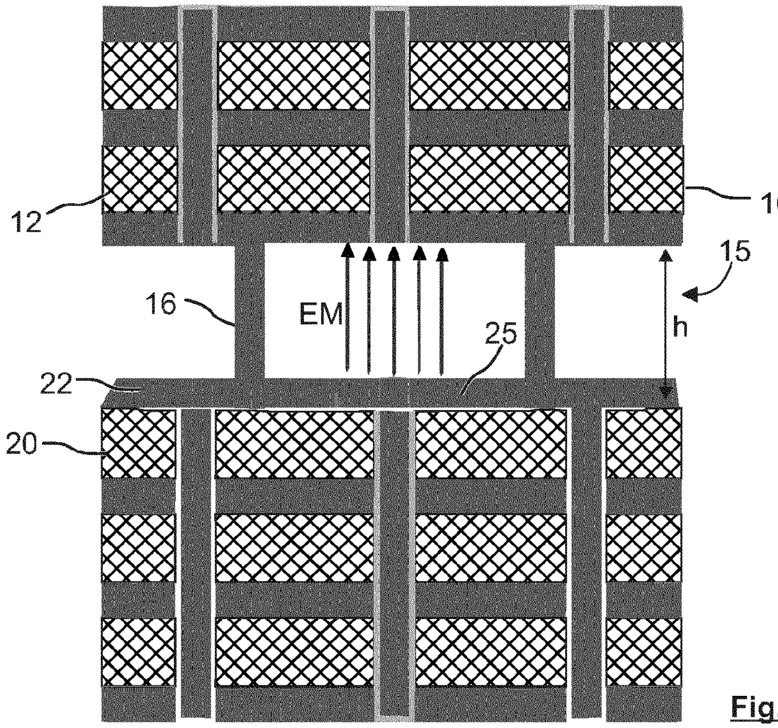

Fig. 6

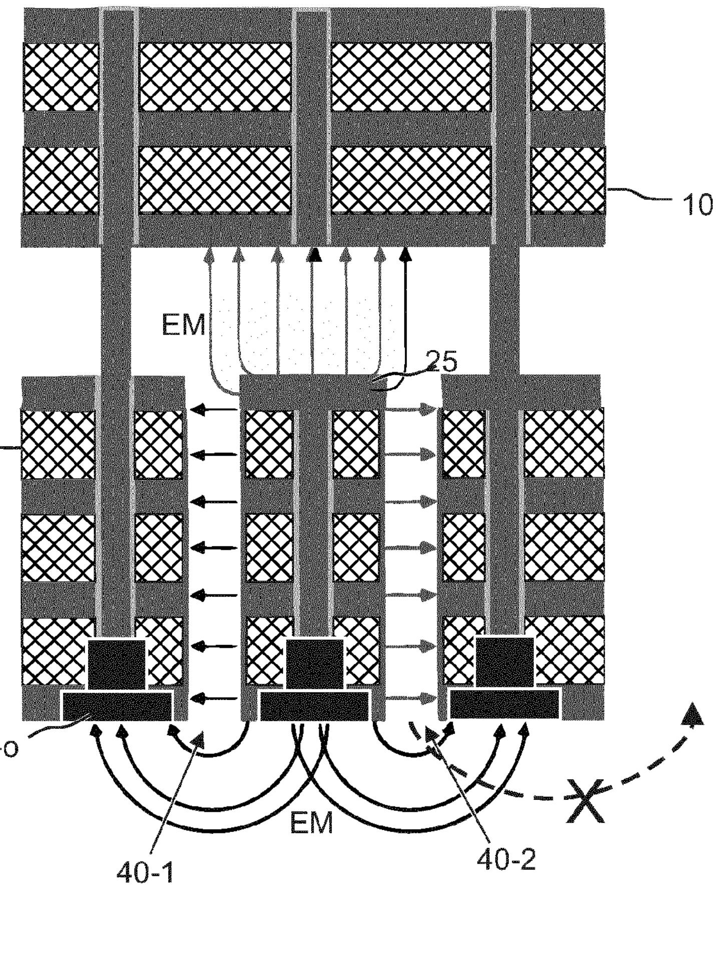

Fig. 7

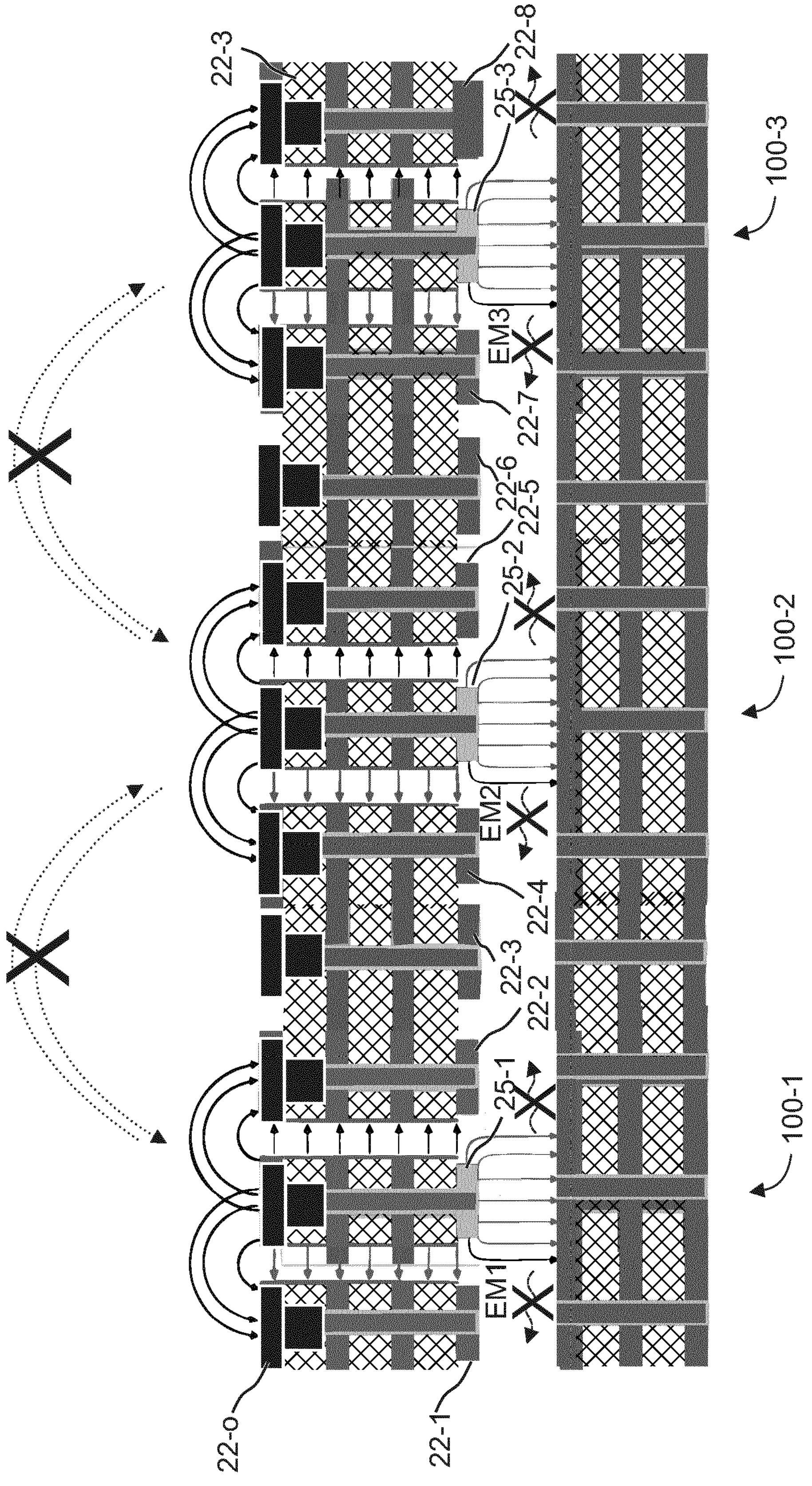
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Fig. 8

Europäisches Patentamt
European Patent Office
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EUROPEAN SEARCH REPORT

Application Number
EP 23 19 7945

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	RAZAVI SEYED ALI ET AL: "2$\times$ 2-Slot Element for 60-GHz Planar Array Antenna Realized on Two Doubled-Sided PCBs Using SIW Cavity and EBG-Type Soft Surface fed by Microstrip-Ridge Gap Waveguide", IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, IEEE, USA, vol. 62, no. 9, 1 September 2014 (2014-09-01), pages 4564-4573, XP011558054, ISSN: 0018-926X, DOI: 10.1109/TAP.2014.2331993 [retrieved on 2014-09-01]	1,2,4, 6-15	INV. H01Q1/52 H01Q15/00 H01Q21/00 H01Q21/06 ADD. H01Q1/32
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X	US 2012/119969 A1 (MACDONALD JAMES [US] ET AL) 17 May 2012 (2012-05-17)	1-7, 12-15	
A	* paragraph [0046] - paragraph [0114]; figures 1-25 *	9	
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A	* paragraph [0010] - paragraph [0058]; figures 1-10 *	5	

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A	* paragraph [0156] - paragraphs [0217], [0254], [0262]; figures 9-16,24G,22 *	7,8	

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	13 February 2024	Sípal, Vít

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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D : document cited in the application
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13-02-2024

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