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(71) Applicant: HUAWEI TECHNOLOGIES CO., LTD. [CN/CN]; Huawei Administration Building Bantian Longgang District, Shenzhen, Guangdong 518129 (CN).

(72) Inventor; and
(71) Applicant *(for US only)*: **GIUSTO, Roberto** [IT/IT]; Huawei Technologies Duesseldorf GmbH, Riesstr. 25, 80992 Munich (DE).

(72) Inventor: **MORGIA, Fabio**; Huawei Technologies Duesseldorf GmbH, Riesstr. 25, 80992 Munich (DE).

(74) Agent: **KREUZ, Georg**; Huawei Technologies Duesseldorf GmbH, Riesstr. 25, 80992 Munich (DE).

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(54) **Title:** COMPOSITE ARTIFICIAL DIELECTRICS AND MULTIBAND ANTENNA FEEDER

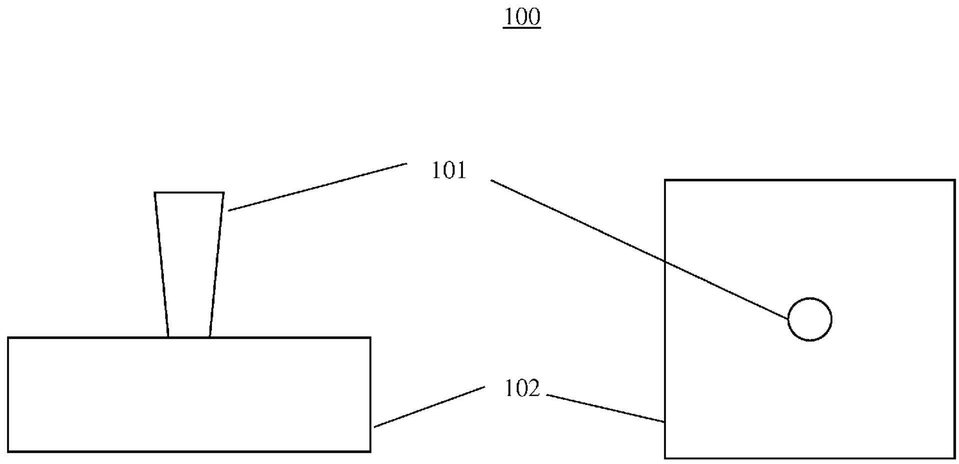

FIG. 1

(57) **Abstract:** The present invention provides an antenna feeder assembly, and a multi-band microwave antenna comprising the antenna feeder assembly. The antenna feeder assembly comprises a first feeder attached to a second feeder, the first feeder being configured to propagate electromagnetic waves of a first frequency band and the second feeder being configured to propagate electromagnetic waves of a second frequency band lower than the first frequency band, wherein: the first feeder is horn-shaped and is formed by at least one first dielectric material; and the second feeder comprises an array of radiating elements and a sub- wavelength elements layer having an anisotropic index of refraction. The multi-band microwave antenna comprises a dish reflector, a sub-reflector, and an antenna feeder assembly according to the aforementioned embodiments of the present invention. The specific design of the antenna feeder assembly enables a multi-band dual-polarization operation of a properly configured high-gain dual-reflector (very low-cost) antenna.

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COMPOSITE ARTIFICIAL DIELECTRICS AND MULTIBAND ANTENNA FEEDER

TECHNICAL FIELD

The present invention relates to an antenna feeder assembly and a multi-band antenna, and in particular, to an artificial “All-dielectric” feeder assembly used to transmit and/or receive electromagnetic radiation.

BACKGROUND

Low-cost multi-band dual-polarization antennas are required for Backhaul Radio-links either at traditional microwave bands or at millimeter-wave bands. However, low-cost dish antennas are known to perform dual-polarization, but their operation is in single-band only, essentially because the limitations of their self-supported feeders, either as HAT-Feed types or as other types of Rear-Feed.

Single-band dish antennas, deployed as many as for 3 millions of Backhaul Microwave Links, achieve high gain at a very reasonable cost; their preferred, lowest-cost, configurations are known either as "Rear-Feed" or self-supported "Hat-Feed".

Dealing with the Hat-Feed we get the advantage of very low cost for dual polarization dish antennas, while high performance can be achieved only for single-band operation. However, the design of highly efficient antennas for multi-band dual-polarization operation requires additional degrees of freedom, as provided by dual-reflector antenna configurations; however, the manufacturing cost increases according to the complexity and the dimensions of the antenna.

The attempts of performing dual-band operation with dual-polarization Rear-Feeds have demonstrated poor results. Therefore, it is desired to have a new innovative feeder design, which is valid for dual-reflector antenna configurations and also applicable to one-band or dual-band dual-polarization Rear-Feed type of Antennas.

SUMMARY

In view of the above-mentioned problems and limitations, embodiments of the present invention improve the conventional antenna assembly.

An objective is achieved by the embodiments as provided in the enclosed independent claims. Advantageous implementations of the embodiments of the present invention are further defined in the dependent claims.

A first aspect of the invention provides an antenna feeder assembly for a multi-band antenna, the antenna feeder assembly comprising a first feeder attached to a second feeder, the first feeder being configured to propagate electromagnetic waves of a first frequency band and the second feeder being configured to propagate electromagnetic waves of a second frequency band lower than the first frequency band, wherein: the first feeder is horn-shaped and is formed by at least one first dielectric material; and the second feeder comprises an array of radiating elements and a sub-wavelength elements layer having an anisotropic index of refraction.

The proposed antenna feeder assembly is a combination of a dielectric feeder operated on higher frequencies and an array structure feeder operated on lower frequencies. The peculiar characteristic of the proposed "All-dielectric" artificial structure is the anisotropic index of refraction, where the index of refraction in the axial direction of wave propagation, is different from the index of refraction in the direction of the plane transverse with respect to this axis. The antenna feeder assembly and a corresponding multi-band antenna is provided, allows to enable either a dual-band or, eventually, a multiple-band operation of a properly configured high-gain dual-reflector (very low-cost) antenna.

In an implementation form of the first aspect, the sub-wavelength elements of the sub-wavelengths elements layer are filled with at least one second dielectric material.

The second feeder may be made of the array of radiating elements plus an additional artificial structure of sub-wavelength elements, for instance, made of all-dielectric materials.

In an implementation form of the first aspect, the sub-wavelengths elements layer includes a dielectric crystal, in particular a low fill-factor and/or low-index dielectric crystal.

The second feeder may particularly have a layered structure, which comprises a low fill-factor and/or low-index dielectric crystal layer.

In an implementation form of the first aspect, an index of refraction of the sub-wavelength elements layer in an axial direction of electromagnetic wave propagation is positive but less than one, and an index of refraction of the sub-wavelength elements layer in the plane transverse to the axial direction is a value between one and the index of refraction of the at least one second dielectric material of the sub-wavelength elements layer.

Due to the characteristic of anisotropic index of refraction, the index of refraction of the sub-wavelength elements layer in an axial direction of electromagnetic wave propagation is positive, but near one or less than one.

In an implementation form of the first aspect, the sub-wavelength elements layer is arranged on top of the array of radiating elements.

The second feeder thus has a layered structure, in particular, the sub-wavelength elements layer is located on top of the array structure.

In an implementation form of the first aspect, the sub-wavelength elements layer is entirely formed by the at least one second dielectric material.

The sub-wavelength elements layer of the second feeder may be made of dielectric materials only.

In an implementation form of the first aspect, the array of radiating elements is a 4 x 4 array for dual-polarization operation and comprises an independent waveguide port for each polarization.

Two independent waveguide ports enable the dual-polarization operation of the proposed feeder assembly.

In an implementation form of the first aspect, the second feeder comprises at least one of a plurality of coaxial sub-wavelength elements layers and a plurality of planar sub-wavelength elements layers.

Manifold Layers of the proposed sub-wavelength elements can be properly structured/optimized in order to confine the electromagnetic field and to perform the required conditioning of the feeder radiation pattern.

In an implementation form of the first aspect, the second feeder comprises a Fabry-Pérot resonator.

The Fabry-Pérot resonator comprises all-dielectric cavities. A “Super-Gain” is expected by creating the Fabry-Pérot resonator.

In an implementation form of the first aspect, the first feeder comprises a dielectric emitting section and a dielectric radiating section and an inner cavity; and the dielectric emitting section includes a wall and first sub-wavelength elements arranged along the longitudinal direction of the first feeder on or in an external surface of the wall, wherein the first sub-wavelength element has a dielectric constant different than the dielectric constant of the dielectric emitting section.

The first sub-wave element or structure element may have a circular shape. The first sub-wave element may have several dimensions such as width, length, height, or diameter.

In an implementation form of the first aspect, the first feeder is made entirely of the at least one first dielectric material.

The first feeder is made of dielectric materials only. The first feeder may be made of several dielectric materials with different dielectric constants.

In an implementation form of the first aspect, a frequency band ratio of the first frequency band and the second frequency band is smaller than 2.

For instance, the first feeder and the second feeder may operate on 38GHz band and E-band, respectively. Or the first feeder and the second feeder may operate on 32GHz band and 18GHz band, respectively.

A second aspect of the invention provides a multi-band microwave antenna, comprising a dish reflector, a sub-reflector, and an antenna feeder assembly according to the aforementioned first aspect of the present invention.

The antenna feeder assembly according to the first aspect and its implementation forms may be used in an antenna, for example, an Antenna with a Side-Fed Cassegrain/Dual-Reflector configuration.

It has to be noted that all devices, elements, units and means described in the present application could be implemented in the software or hardware elements or any kind of combination thereof. All steps which are performed by the various entities described in the present application as well as the functionalities described to be performed by the various entities are intended to mean that the respective entity is adapted to or configured to perform the respective steps and functionalities. Even if, in the following description of specific embodiments, a specific functionality or step to be performed by external entities is not reflected in the description of a specific detailed element of that entity which performs that specific step or functionality, it should be clear for a skilled person that these methods and functionalities can be implemented in respective software or hardware elements, or any kind of combination thereof.

BRIEF DESCRIPTION OF DRAWINGS

The above described aspects and implementation forms of the present invention will be explained in the following description of specific embodiments in relation to the enclosed drawings, in which

FIG. 1 shows a schematic front view and a top view of an antenna feeder assembly according to an embodiment of the present invention.

FIG. 2 shows an antenna feeder assembly according to an embodiment of the present invention.

FIG. 3 shows a 4×2 array structure according to an embodiment of the present invention.

FIG. 4 shows a second feeder according to an embodiment of the present invention.

FIG. 5 shows an antenna feeder assembly according to an embodiment of the present invention.

FIG. 6 shows a multi-band microwave antenna according to an embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

The embodiments of the present invention provide a new type of multi-Band feeder, made of very low loss dielectric material, e.g. Teflon, essentially manufactured according to a sub-wavelength composite structure, designed as artificial structure of “All-dielectric” meta-material (Dielectric Crystal), enabling either a dual-band or, eventually, a multiple-band operation of a properly configured high-gain dual-reflector (very low-cost) antenna.

FIG. 1 shows a design of an antenna feeder assembly 100, in particular, it shows a first feeder 101 according to an embodiment of the invention, attached to a second feeder 102 according to an embodiment of the invention. The first feeder 101 may be attached to the center of the second feeder 102, which is specifically designed to meet all the requirements, for example, to enable the co-location and a scalability of the phase centers. In particular, the phase center, i.e. the point from which the electromagnetic radiation spreads spherically outward, is very sensitive to the frequency band, at which the antenna works. In particular, the position of the phase center of a traditional antenna moves continuously towards the open end portion of the antenna with increasing frequency. Such behavior deteriorates the efficiency, the peak Gain, and the side lobe pattern performance of the antenna. That is, if the antenna is set to have optimal performance within a specific frequency band, the performance of the antenna within a higher frequency band will deteriorate due to the displacement of the phase center. Therefore, a stable and co-located phase center are important for a single dish multi-band antenna.

The first feeder 101 is configured to propagate electromagnetic waves of a first frequency band. The second feeder 102 is configured to propagate electromagnetic waves of a second frequency band. In particular, the second frequency band is lower than the first frequency band.

FIG. 2 shows in more detail an example of the antenna feeder assembly according to an embodiment of the present invention. The first feeder 101 is in particular horn-shaped, or cigar-shaped or rod-shaped, and is formed by at least one first dielectric material. Optionally, a diameter of the first feeder is smaller than one wavelength corresponding to the frequency of the wave in the first frequency band.

The second feeder 102 comprises an array of radiating elements 1021 and a sub-wavelength elements layer having an anisotropic index of refraction. The radiating element 1021 may have a rectangle-like shape. The array of radiating elements 1021 may be an n×m array, with n and m both positive integers. Optionally, n is equal to m. As shown in FIG. 2, the second feeder 102 may comprise a 4×4 array of radiating elements 1021. FIG. 2 depicts a configuration where a 4×4 array performs a single-polarization operation.

Optionally, the sub-wavelength elements of the sub-wavelengths elements layer are filled with at least one second dielectric material. The second dielectric material may have a different dielectric constant compared to the first dielectric material. The first dielectric material and the second dielectric material may be selected based on a specific requirement as to the performance of antennas.

FIG. 3 shows an exemplary 4×2 array of the second feeder 102 according to an embodiment of the present invention. Optionally, on top of the array, an additional dielectric crystal layer 1022 is arranged as depicted in the FIG. 4. In particular, a low fill-factor and/or low-index dielectric crystal may be used. Due to a self-collimation property of this periodic structure crystal, another benefit is that a raw positioning does not affect the gain.

Optionally, the sub-wavelength elements layer of the second feeder 102 may be entirely formed by the at least one second dielectric material. That is, the complete second feeder 102 is made of all-dielectric materials.

Optionally, an index of refraction of the sub-wavelength elements layer in an axial direction of electromagnetic wave propagation may be positive but less than one, e.g. near to one, and an index of refraction of the sub-wavelength elements layer in the plane transverse to the axial direction may be a value between one and the index of refraction of the at least one second dielectric material of the sub-wavelength elements layer.

Optionally, the second feeder 102 may comprise at least one of a plurality of coaxial sub-wavelength elements layers and a plurality of planar sub-wavelength elements layers. Manifold layers of the proposed sub-wavelength elements can be properly structured/optimized, in order to confine the electromagnetic field and to perform the required conditioning of the feeder radiation pattern.

Notably, the idea of adding a composite structure made of a 4×4 array plus a dielectric crystal layer "on top" of its radiating array creates an essentially twofold benefit, as it enables an accurate conditioning of the feeder radiation pattern, meanwhile also the positioning of the phase-center of the feeder can be optimally set or modified according to the dual-band requirements. It substantially improves the performances of the feeder assembly according to this embodiment of the present invention at low-frequency, meanwhile not disturbing the high-frequency operation of the "All-dielectric" inner feeder (e.g. for E-band operation).

Optionally, the second feeder 102 may comprise a Fabry-Pérot resonator 1023. The Fabry-Pérot resonator 1023 comprises all-dielectric cavities. A "Super-Gain" is expected by creating the Fabry-Pérot resonator.

FIG. 5 shows an example of the antenna feeder 100 assembly performing a dual-polarization operation according to an embodiment of the present invention. The second feeder 102 comprises a 4×4 array for dual-polarization operation and comprises an independent waveguide port 1024 for each polarization.

It should be noted that the above described feeder assembly is very compact, because this type of feeder is very low-profile. Moreover, it does not need an orthomode transducer (OMT), as two independent waveguide ports are coupling the corresponding two different linear polarization modes of feeder radiation.

Normally, a relevant “turnstile-OMT” is required for operating the dual-polarization of a horn-shaped feeder over a wide bandwidth. Such OMT has large dimensions and needs further space, especially when dealing with low-frequencies (e.g. 15 GHz). Besides that, when a required frequency band ratio (if it is desired to operate on two different frequency bands) is smaller than 2 (e.g. E-band and 38 GHz band or 18 GHz band and 32 GHz band), it is quite critical to achieve such requirements, as a complex realization of an OMT for a dual-polarization operation which includes waveguide filters is mandatory.

Therefore, thanks to the implementation of the feeder assembly according to the embodiments of the present invention, an OMT is not required for operating the lowest-frequency band. As the 4×4 array of dual-polarization radiating elements have two independent waveguide ports, the corresponding linear polarization operation of this multi-band feeder assembly is enabled. Thus, a cost is reduced due to the fact that the OMT is not required. In addition, the cost is further reduced due to the very compact dimensions of the feeder assembly according to the embodiments of the present invention.

In addition, the first feeder 101 of this invention may comprise a dielectric emitting section and a dielectric radiating section and an inner cavity; and the dielectric emitting section includes a wall and first sub-wavelength elements arranged along the longitudinal direction of the first feeder on or in an external surface of the wall, wherein the first sub-wavelength element has a dielectric constant different than the dielectric constant of the dielectric emitting section.

Optionally, the first feeder 101 may be made entirely of the at least one first dielectric material. That is, the first feeder 101 is an “All-dielectric” feeder. The first feeder may be made of several dielectric materials with different dielectric constants.

Optionally, the feeder assembly 100 may be applied to the first frequency band and the second frequency band with a frequency band ratio smaller than 2. For instance, the first feeder 101 may operate on E-band, the second feeder 102 may operate on 38 GHz band; or the first feeder 101 may operate on 32 GHz band, the second feeder 102 may operate on 18 GHz band.

A possible way of using the antenna feeder assembly according to the embodiments of the present invention is in an antenna with a Side-Fed Cassegrain/Dual-Reflector configuration. As depicted in FIG. 6, a multi-band microwave antenna 1 is provided, comprising a dish reflector 2, a sub-reflector 3, and an antenna feeder assembly 100 according to the aforementioned embodiments of the present invention.

The antenna feeder assembly 100 shown in FIG. 6 may be the same antenna feeder assembly 100 as shown in FIG. 1, FIG. 2 and FIG. 4, respectively.

In summary, the embodiments of the present invention achieve multiple benefits. The advantages can be summarized as:

1) Cost Reduction, due to the fact that OMT is not required for operating the lowest-frequency band, as the 4×4 array of dual-polarization radiating elements have two independent waveguide ports, which enable the corresponding linear polarization operation polarization of this multi-band feeder assembly.

2) Cost Reduction, due to the very compact dimensions of the multi-band feeder assembly; indeed, a very compact mechanical structure is viable for the overall antenna.

3) The proposed composite structure (made of a 4×4 array plus a dielectric crystal “on top” of its radiating aperture) creates an essentially twofold benefit, as it enables an accurate conditioning of the feeder radiation pattern, meanwhile also the positioning of the phase-center of the feeder can be optimally set or modified according to the dual-band requirements.

4) Manifold layers of the proposed sub-wavelength elements can be properly structured/optimized in order to confine the electromagnetic field and to perform the required conditioning of the feeder radiation pattern according to: excellent rotational

symmetry, lowest sidelobes, minimum frequency-sensitivity of the feeder phase-center position and overall best efficiency, lowest loss.

The present invention has been described in conjunction with various embodiments as examples as well as implementations. However, other variations can be understood and effected by those persons skilled in the art and practicing the claimed invention, from the studies of the drawings, this disclosure and the independent claims. In the claims as well as in the description the word “comprising” does not exclude other elements or steps and the indefinite article “a” or “an” does not exclude a plurality. A single element or other unit may fulfill the functions of several entities or items recited in the claims. The mere fact that certain measures are recited in the mutual different dependent claims does not indicate that a combination of these measures cannot be used in an advantageous implementation.

Claims

1. An antenna feeder assembly (100) for a multi-band antenna, the antenna feeder assembly (100) comprising a first feeder (101) attached to a second feeder (102), the first feeder (101) being configured to propagate electromagnetic waves of a first frequency band and the second feeder (102) being configured to propagate electromagnetic waves of a second frequency band lower than the first frequency band, wherein:

the first feeder (101) is horn-shaped and is formed by at least one first dielectric material; and

the second feeder (102) comprises an array of radiating elements (1021) and a sub-wavelength elements layer having an anisotropic index of refraction.

2. The feeder assembly (100) according to claim 1, wherein:

the sub-wavelength elements of the sub-wavelengths elements layer are filled with at least one second dielectric material.

3. The feeder assembly (100) according to claim 1 or 2, wherein:

the sub-wavelengths elements layer includes a dielectric crystal (1022), in particular a low fill-factor and/or low-index dielectric crystal.

4. The feeder assembly (100) according to any of claims 1 to 3, wherein:

an index of refraction of the sub-wavelength elements layer in an axial direction of electromagnetic wave propagation is positive but near one or less than one, and

an index of refraction of the sub-wavelength elements layer in the plane transverse to the axial direction is a value between one and the index of refraction of the at least one second dielectric material of the sub-wavelength elements layer.

5. The feeder assembly (100) according to any of claims 1 to 4, wherein:

the sub-wavelength elements layer is arranged on top of the array of radiating elements (1021).

6. The feeder assembly (100) according to any of claims 1 to 5, wherein:

the sub-wavelength elements layer is entirely formed by the at least one second dielectric material.

7. The feeder assembly (100) according to any of claims 1 to 6, wherein:
the array of radiating elements (1021) is a 4 x 4 array for dual-polarization operation and comprises an independent waveguide port (1024) for each polarization.

8. The feeder assembly (100) according to any of claims 1 to 7, wherein:
the second feeder (102) comprises at least one of a plurality of coaxial sub-wavelength elements layers and a plurality of planar sub-wavelength elements layers.

9. The feeder assembly (100) according to any of claims 1 to 8, wherein:
the second feeder (102) comprises a Fabry-Pérot resonator (1023).

10. The feeder assembly (100) according to any of claims 1 to 9, wherein:
the first feeder (101) comprises a dielectric emitting section and a dielectric radiating section and an inner cavity; and
the dielectric emitting section includes a wall and first sub-wavelength elements arranged along the longitudinal direction of the first feeder on or in an external surface of the wall, wherein the first sub-wavelength element has a dielectric constant different than the dielectric constant of the dielectric emitting section.

11. The feeder assembly (100) according to any of claims 1 to 10, wherein:
the first feeder (101) is made entirely of the at least one first dielectric material.

12. The feeder assembly (100) according to any of claims 1 to 11, wherein:
a frequency band ratio of the first frequency band and the second frequency band is smaller than 2.

13. A multi-band microwave antenna (1), comprising a dish reflector (2), a sub-reflector (3), and an antenna feeder assembly (100) according to any one of the preceding claims.

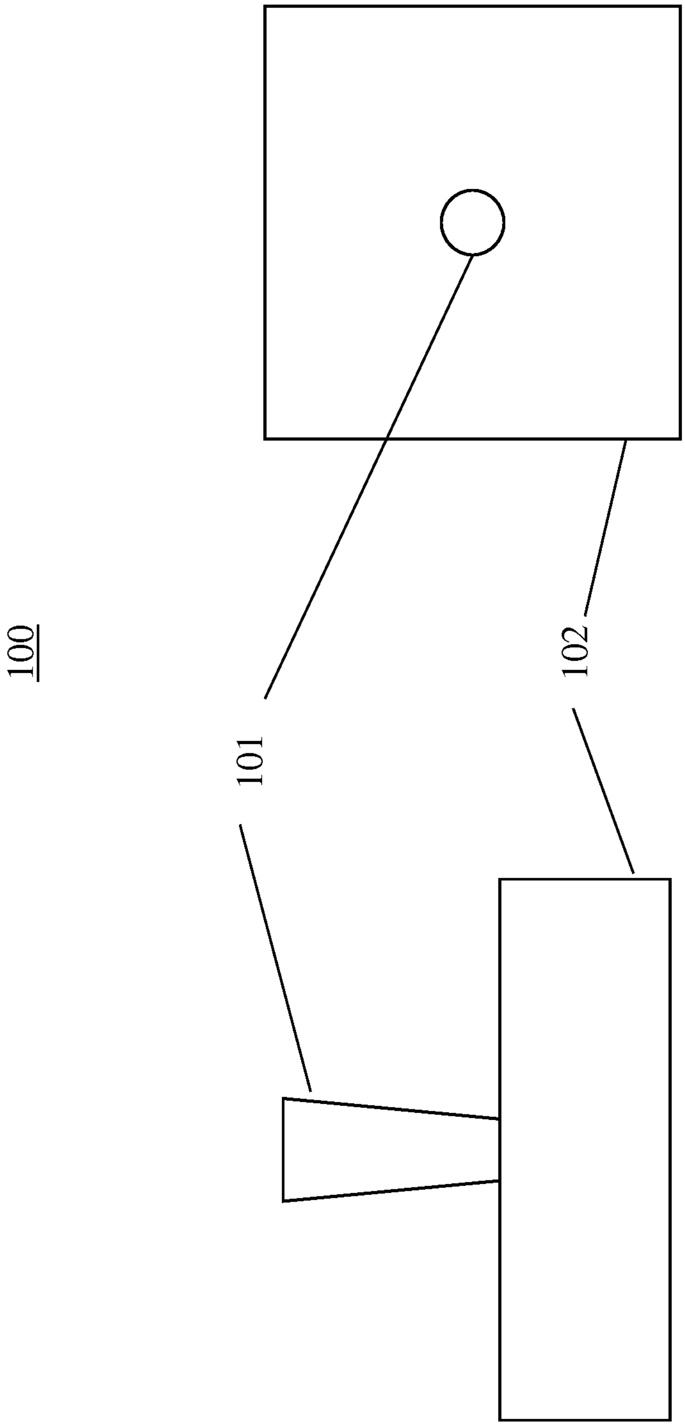

FIG. 1

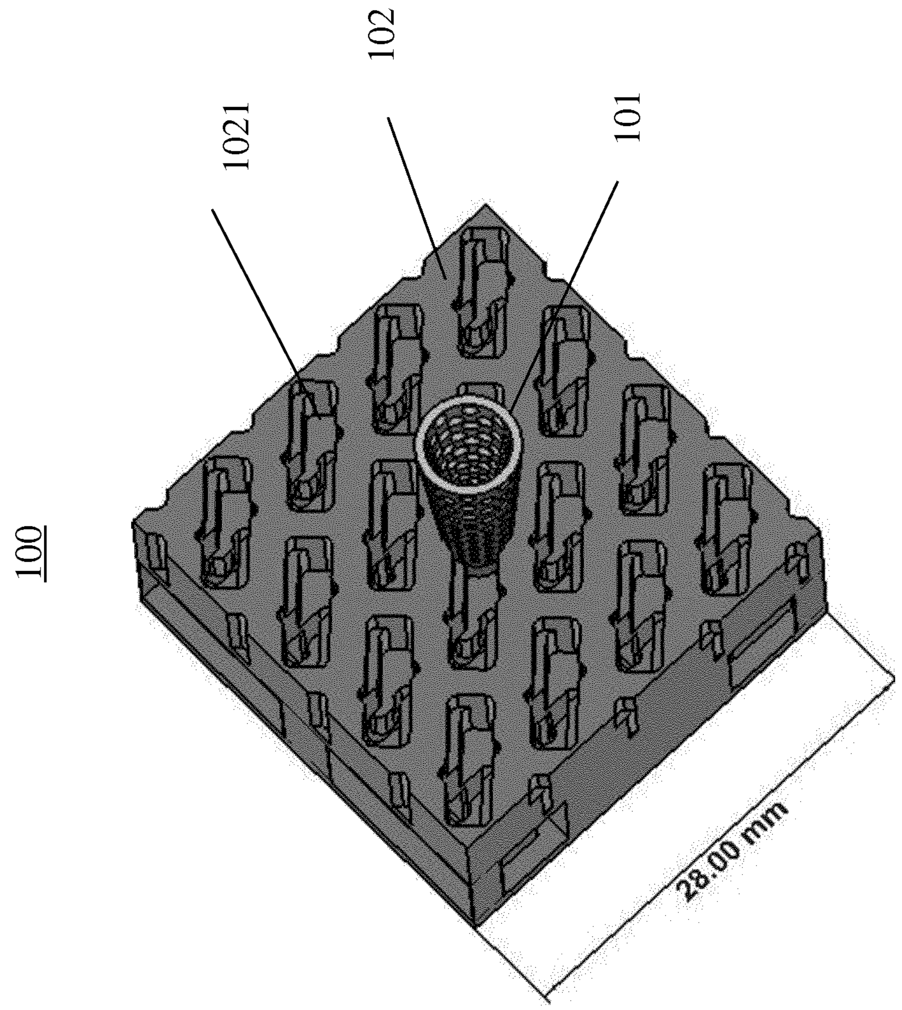

FIG. 2

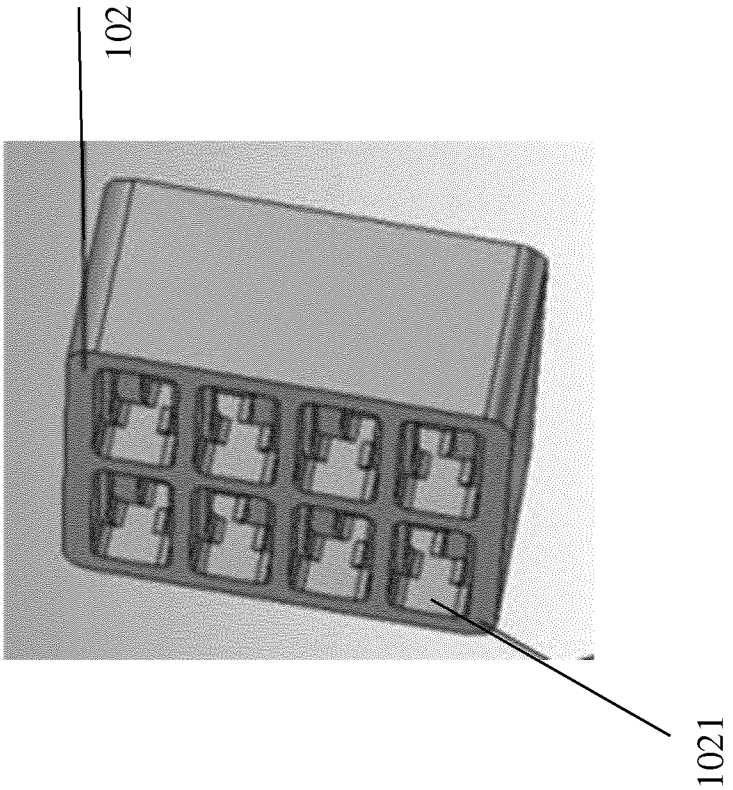

FIG. 3

102

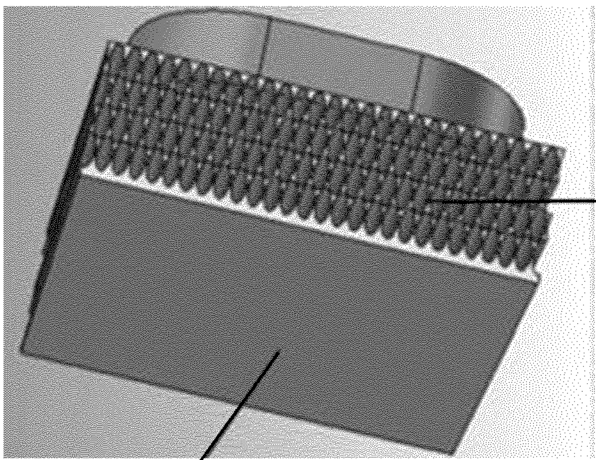

FIG. 4

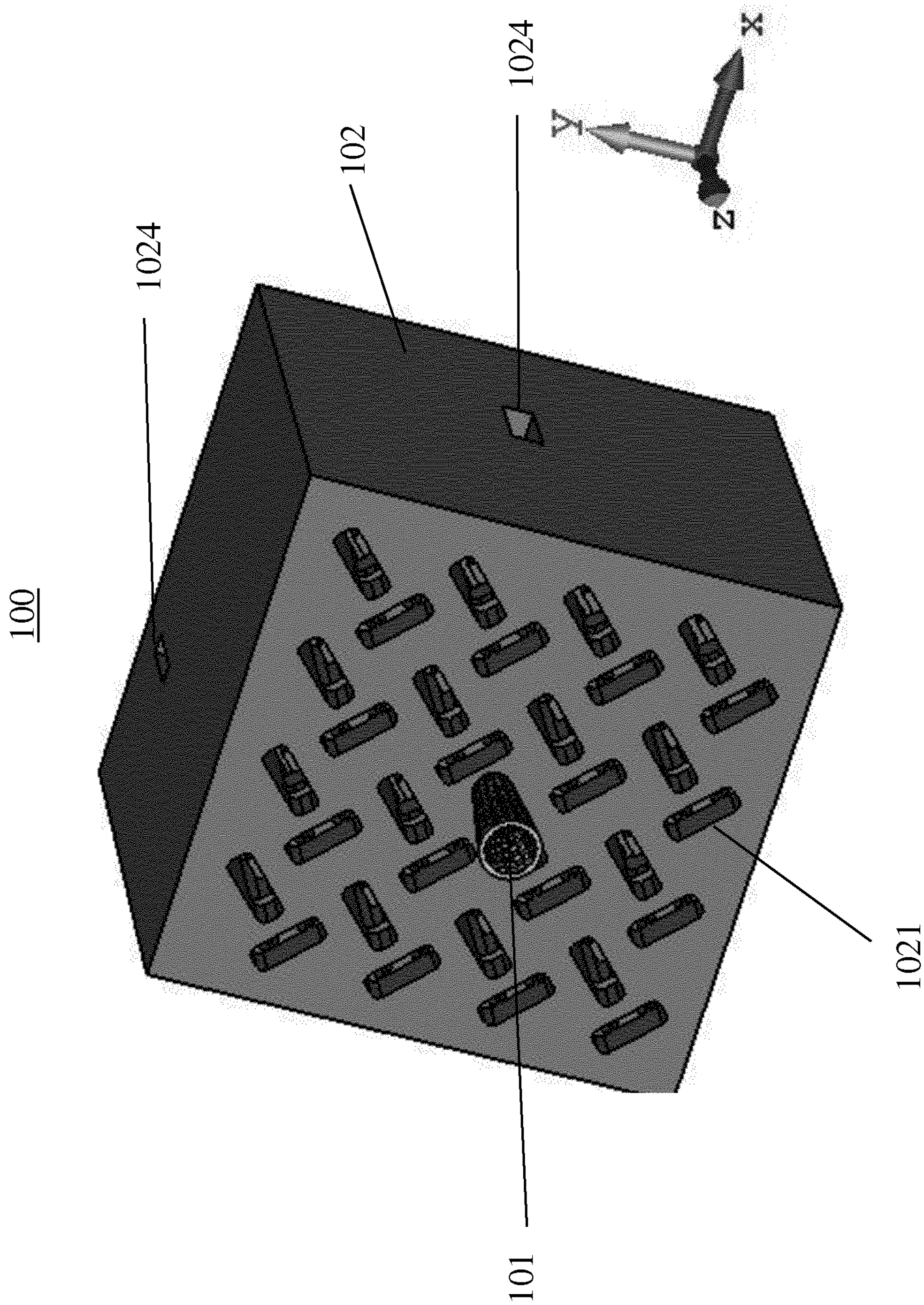

FIG. 5

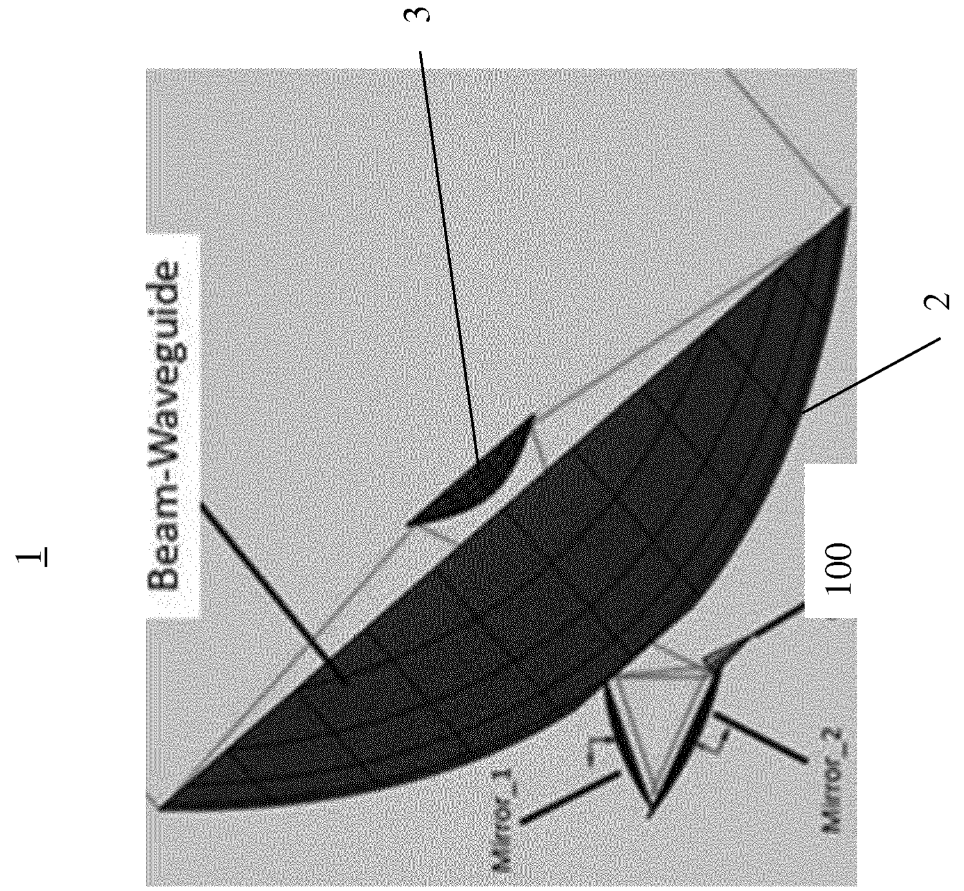

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/058539

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01Q19/17 H01Q19/19 H01Q5/45 H01Q13/28
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP S60 18004 A (NIPPON TELEGRAPH & TELEPHONE) 30 January 1985 (1985-01-30) figure 2 figure 4 figure 6 page 2, line 5 - line 6 page 2, line 12 - line 17 -----	1-13

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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

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

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Date of the actual completion of the international search	Date of mailing of the international search report
25 November 2019	29/11/2019

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

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/058539

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	RANJBAR AMIN ET AL: "All-dielectric bianisotropic metasurfaces", 2017 IEEE INTERNATIONAL SYMPOSIUM ON ANTENNAS AND PROPAGATION & USNC/URSI NATIONAL RADIO SCIENCE MEETING, IEEE, 9 July 2017 (2017-07-09), pages 1719-1720, XP033230111, DOI: 10.1109/APUSNCURSINRSM.2017.8072902 [retrieved on 2017-10-18] figure 1 Section I -----	2-4,6-8
A	YUEHE GE ET AL: "The Use of Simple Thin Partially Reflective Surfaces With Positive Reflection Phase Gradients to Design Wideband, Low-Profile EBG Resonator Antennas", IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 60, no. 2, 24 October 2011 (2011-10-24), pages 743-750, XP011403556, ISSN: 0018-926X, DOI: 10.1109/TAP.2011.2173113 figure 1 Section I -----	9
A	WO 2019/001736 A1 (HUAWEI TECH CO LTD [CN]; GIUSTO ROBERTO [IT]) 3 January 2019 (2019-01-03) page 10, line 3 - line 13 figure 4a -----	10,11

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2019/058539

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