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(71) Applicant: **Valeo Comfort and Driving Assistance**
94046 Créteil Cedex (FR)

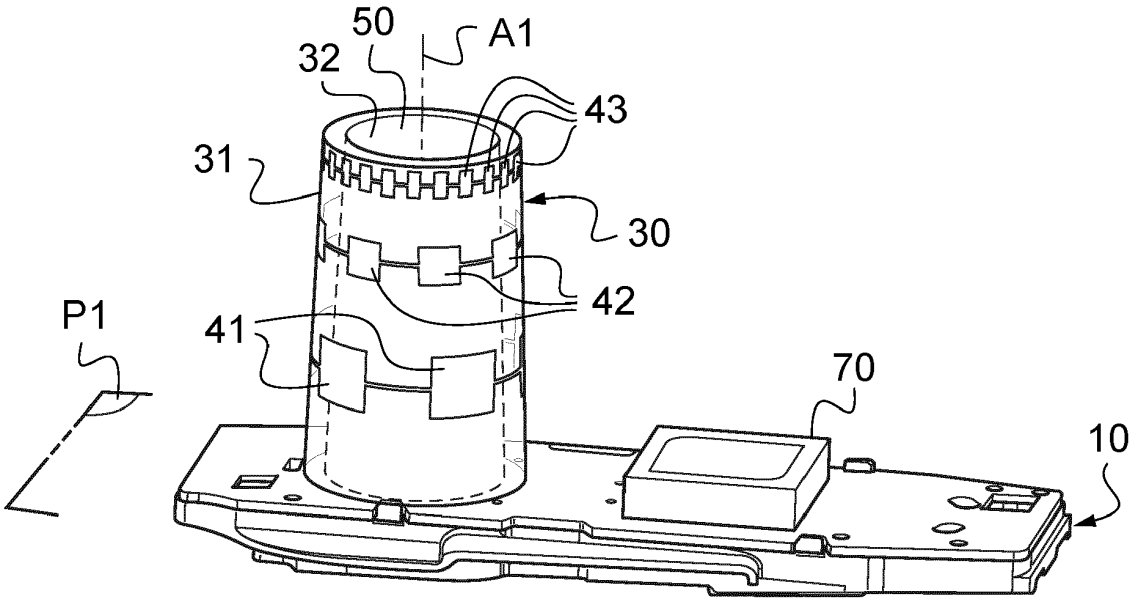
(72) Inventors:
- **MIHAIUTI, Adrian**
  94046 Créteil Cedex (FR)
- **OCH, Marcus**
  94046 Créteil Cedex (FR)

(74) Representative: **Delaval, Guillaume Laurent**
VALEO Comfort and Driving Assistance
76, rue Auguste Perret
Z.I. Europarc
94046 Créteil Cedex (FR)

(54) **AUTOMOTIVE MIMO ANTENNA SYSTEM FOR 5G STANDARD AND BEYOND**

(57) The invention relates to an antenna system (1) to be mounted on a vehicle, comprising:
- a chassis (10),
- a printed circuit board (20) fixed to the chassis and defining a main plane (P1), and
- a dielectric carrier (30) that extends along a main axis (A1) perpendicular or tilted relative to said main plane and that has a side face fitted with several antennas electrically connected to the printed circuit board.

Fig.2



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Description

TECHNICAL FIELD OF THE INVENTION

[0001] The invention relates to a telematics system, and specifically to multiple input multiple output antennas (also called MIMO antennas).

[0002] More broadly, the invention relates to an antenna system to be mounted on a vehicle.

[0003] It also applies to a vehicle fitted with such an antenna system.

BACKGROUND INFORMATION AND PRIOR ART

[0004] Various types of antennas are used in the automotive industry to implement various applications (radio, navigation, telephony...).

[0005] Multiband antenna systems are also commonly used in the automotive industry. Such an antenna system includes a small number of antennas (typically three or four antennas) to cover and operate at multiple frequency ranges and/or for redundancy reasons.

[0006] An antenna system can be installed on the roof surface of a vehicle to let the antennas have an unobstructed view overhead. This antenna system is generally connected to one or more electronic devices (e.g., a cellular phone) inside the passenger compartment of the vehicle, such that the antenna system is operable for transmitting and/or receiving signals to/from the electronic device inside the vehicle.

[0007] The main problem of such an antenna system is that its capacity (in terms of simultaneous communications) and its coverage (in terms of distance) remain reduced. This problem becomes more and more significant with the development of the needs of communication between the vehicle and the outside, especially due to the development of the 5G standard.

SUMMARY OF THE INVENTION

[0008] A purpose of the invention is to provide an antenna system having a better capacity and coverage.

[0009] The above purpose is achieved according to the invention by providing an antenna system to be mounted on a vehicle, comprising:

- a chassis,
- a printed circuit board fixed to the chassis and defining a main plane, and
- a dielectric carrier that extends along a main axis perpendicular or tilted relative to said main plane and that has a side face fitted with several antennas electrically connected to the printed circuit board.

[0010] Thanks to the invention, the antenna system has an array of antennas disposed in such a manner that its capacity and its coverage can be improved and the interference reduced.

[0011] The position of the antennas on the side face of the dielectric carrier indeed enables a good propagation of electromagnetic waves in any direction around the vehicle.

[0012] The antennas system can for instance be of the Massive MIMO type, with more than twenty antennas.

[0013] A massive MIMO antenna indeed increases the effectiveness of the transmission. It is able to send out a stronger radio signal, with a higher data throughput for greater distances.

[0014] Beamforming is another key wireless technique used by the invention, consisting in focusing a wireless signal in a specific direction, rather than broadcasting to a wide area.

[0015] When the massive MIMO antenna is used in a spectrum of the 5G (for instance from 410MHz until 7125MHz), this solution can be used when the car is driving at low speed through the cities or is stationary.

[0016] Other aspects of the invention are the following ones:

- the dielectric carrier is hollow and has an outer side face that is fitted with said several antennas and an inner side face at least partially coated with a conductive layer;
- the conductive layer is electrically connected to a ground terminal of the printed circuit board;
- the dielectric carrier is directly fixed onto the printed circuit board by means of its conductive layer;
- the dielectric carrier has an essentially rotationally symmetrical shape;
- the dielectric carrier has a cylindrical shape;
- the dielectric carrier has a conical shape, with a top angle preferably lying from 4 degrees to 30 degrees;
- said antennas are regularly distributed all around the dielectric carrier;
- at least one of said antennas has a size different from the size of another one of said antennas;
- first antennas of same size are regularly distributed all around the dielectric carrier, at a first height relative to said printed circuit board;
- second antennas of same size are regularly distributed all around the dielectric carrier, at a second height relative to said printed circuit board distinct from said first height, the size of said first antennas being different from the size of said second antennas;
- the antenna system comprises a finishing cover, said finishing cover and said chassis encasing the dielectric carrier;
- the finishing cover has a shark-fin shape;
- the antenna system comprises another antenna fixed to the printed circuit board, at a distance from said dielectric carrier.

[0017] The invention also relates to a vehicle comprising a roof and an antenna system as defined above, fixed to the roof so that said dielectric carrier extends at least

partially above the roof.

[0018] Preferably, said chassis extends between said roof and said printed circuit board, above or below said roof.

DETAILED DESCRIPTION OF EXAMPLES

[0019] The following description with reference to the accompanying drawings, given by way of non-limiting examples makes it clear what the invention consists in and how it can be reduced to practice.

[0020] In the accompanying drawings:

- Figure 1 is a schematic view in perspective of a vehicle comprising an antenna system according to the invention;
- Figure 2 is a schematic view in perspective of a part of an antenna system according to a first embodiment of the invention;
- Figure 3 is a schematic cross-sectional view of the entire antenna system of Figure 2;
- Figure 4 is a schematic cross-sectional view in perspective of a part of an antenna system according to a second embodiment of the invention;
- Figure 5 is a schematic cross-sectional view of the carrier of the antenna system of Figure 4;
- Figure 6 is a schematic side view of a truncated cone; and
- Figure 7 is a graphic illustrating the variation of a best bottom angle of the truncated cone of Figure 6 as a function of a distance between the antenna system and a base station.

[0021] Figure 1 represents a vehicle 100 having a roof 101 fitted with an antenna system 1. This vehicle can be of any type: car, truck, motorcycle, etc.

[0022] In the description, the terms "upper" and "lower" (and their derivations) are used relative to this vehicle, the latter being considered as running on a horizontal road. Thus, the upper of an element designates the side of the element that faces the sky, and the lower designates the opposite side.

[0023] The antenna system 1 can be used for ensuring a wireless communication between the vehicle equipment (or the vehicle passengers equipment) and the outside world, in terms of satellite navigation, satellite radio, car access, telephony, etc.

[0024] This antenna system 1 comprises an antenna module and a telematics control unit suitable to process the signal received from the antenna module and/or to send a signal to this antennas module so as to transmit this signal in a specific direction. This telematics control unit is connected to the vehicle equipment to send it the processed received signals.

[0025] A first embodiment of the antenna system 1 is shown in Figures 2 and 3, and a second embodiment of this system is shown in Figures 4 and 5.

[0026] In both represented embodiments, the antenna system 1 is particularly designed for ensuring communications with a 5G base station, according to the 5G standard.

[0027] Consequently, the minimum requirements of the antenna system 1 are:

- for peak data rate: a downlink of 20 Gbit/s and an uplink of 10 Gbit/s,
- for peak spectral efficiencies: a downlink of 30 bit/s/Hz and an uplink of 15 bit/s/Hz,
- a user plane latency (for a single user and small packets): 4 ms for enhanced Mobile Broadband (eMBB) and 1 ms for Ultra-Reliable Low-Latency Communication (URLLC),
- a control plane latency lying between 10 and 20ms, and
- a maximum aggregated system bandwidth: at least 100 MHz, up to 60GHz in higher frequency bands.

[0028] Here, two frequency bands can be used: First there is the Frequency Range number 1 (FR1) from 410 MHz to 7125 MHz. The other and preferred Frequency Range number 2 (FR2) includes frequency bands from 24.25 GHz to 52.6 GHz.

[0029] To this end, according to the invention, the antenna system 1 includes a chassis 10; 110, a printed circuit board 20; 120 fixed to the chassis 10; 110, a dielectric carrier 30; 130 carrying several antennas 41, 42, 43, and a finishing cover 60 that protects at least these antennas.

[0030] The chassis 10; 110 is designed to be fixed on the vehicle. In a variant, it could include or be formed by the roof of the vehicle.

[0031] In both embodiments, the chassis 10; 110 is a dielectric support for the printed circuit board 20; 120.

[0032] In the first embodiment shown in Figures 2 and 3, it comprises a molded piece of plastic comprising a plate that that is essentially flat and that is shaped so as to be fixed horizontally, above the roof 101 of the vehicle 100.

[0033] This chassis 10; 110 comprises fixing means for its fixation to the roof.

[0034] As shown in Fig.2, these fixing means comprise at least one hole 11 enabling the screwing of the chassis on the roof.

[0035] This chassis 10; 110 also comprises fastening means for fastening the printed circuit board 20; 120.

[0036] Here, these fastening means comprise ribs 12 that extend on the upper face of the plate of the chassis 10, the top faces of the ribs 12 all extending in a same plane so that the printed circuit board 20 can rest on these top faces.

[0037] The fastening means also include snap-fastening teeth suitable to hook the upper face of the printed circuit board 20 in order to block it on the ribs 12.

[0038] Thanks to the ribs 12, when the printed circuit board 20 rests on the chassis 10, these two components delimit between them a space that houses some of the

electronic components of the printed circuit board 20.

[0039] In the second embodiment shown in Figures 4 and 5, the chassis 110 comprises a molded piece of plastic comprising a plate that is essentially flat and that is shaped so as to be fixed horizontally, under the roof 101 of the vehicle 100.

[0040] Here again, this chassis 110 comprises at least one hole 11 enabling its screwing to the roof. He also includes snap-fastening teeth suitable to hook the lower face of the printed circuit board 120.

[0041] In both embodiments, the printed circuit board 20; 120 includes a dielectric plate onto which bands of copper (or other conductive material) are situated, and electronic components soldered onto the dielectric plate to both electrically connect and mechanically fasten them to it.

[0042] This printed circuit board 20; 120 carries the telematics control unit. In a variant, this unit can be carried by another printed circuit board situated in another place into the vehicle.

[0043] The printed circuit board 20; 120 defines a main plane P1. This main plane P1 is here the median plane of the dielectric plate (see Figure 2).

[0044] The dielectric carrier 30; 130, that carries the antennas, is made of a dielectric material such as a molded plastic.

[0045] This dielectric carrier 30; 130 is hollow and longitudinally extends along a main axis A1 perpendicular or tilted relative to the main plane P1, with an angle greater than 45 degrees. Here, the main axis A1 is perpendicular to the main plane P1.

[0046] Preferably, the main axis A1 extends vertically when the vehicle is situated onto a horizontal road. Because of the roof curvature, if the main plane P1 is not horizontal, it can be necessary to tilt the main axis A1 relative to the main plane P1.

[0047] The dielectric carrier 30; 130 exhibits approximately a symmetry of revolution about the main axis A1.

[0048] As shown in Figures 2 and 3, it comprises a cylindrical shaped wall.

[0049] In the embodiment of Figures 4 and 5, the dielectric carrier 130 comprises a wall having a conical shaped upper part, more specifically a frustoconical shaped upper part 135. This second embodiment is preferred because, as it will be explained hereinafter in more details, it improves the communication with a high base station.

[0050] The dielectric carrier 30; 130 rests by its bottom end on the printed circuit board 20; 120. Its upper end is free and opens toward the outside.

[0051] The inner side face 31 of the wall is partially or, preferably, entirely coated with a conductive layer 50. This layer is made of a conductive material, here a metallic material.

[0052] This conductive layer 50 is electrically connected to the ground terminal of the printed circuit board 20; 102. Consequently, this layer can play the role of an antenna reflector and of feeding ground lines for the antennas.

[0053] This electrical connection between the conductive layer 50 and the printed circuit board 20; 120 forms a mechanical connection that fixes the dielectric carrier 30; 130 to the printed circuit board 20; 120.

[0054] As shown in Fig.3, in the first embodiment, the cylindrical wall thickness of the carrier 30 is constant. As shown in Fig.5, in the second embodiment, a lower part 136 and an upper part 135 of the wall have constant thicknesses, these thicknesses being distinct. This thicknesses difference creates, on the outer side face 131 of this wall, a peripheral ring 133 (see Figure 5) facing downward. On the contrary, the inner face of this wall is continuous. Consequently, this inner face and the outer faces of the lower part and of the upper part of the external face of the dielectric carrier 130 are all frustoconical.

[0055] In both embodiments, the lower part 136 of the carrier 30; 130 has the roles of mechanical fixation and of making the electric connection between the printed circuit board 20; 120 and the antennas. The upper part 135 has the role of carrying the antennas 41, 42, 43.

[0056] The carrier diameter, height and thickness are dictated by the implementation and the requirements of the antenna system 1. But for example, the external diameter can be of 28 mm, the height of 50 mm and the thickness of 3 mm.

[0057] In the first embodiment, the propagation axis of each antenna (that is, in the illustrated embodiments, the axis that is orthogonal to the mean plane of the antenna and that passes through the geometric center of this antenna) extends radially relative to the main axis A1 and horizontally. Consequently, each antenna principally radiates into a horizontal direction, towards the outside.

[0058] In the second embodiment, the propagation axis of each antenna is tilted relative to the horizontal. Consequently, each antenna principally radiates into a tilted direction: towards the outside and upward. This is the preferred solution when the antenna system 1 is designed to communicate with 5G base stations having great heights.

[0059] The top angle α of this truncated cone is lower than 45 degrees. Preferably, this top angle α lies from 4 degrees to 30 degrees. This top angle is defined as the aperture of the truncated cone (or as the maximum angle between two generatrix lines of this cone).

[0060] As shown on Figure 6, considering a bottom angle β of the truncated cone, it can be written:

$$\alpha = 2.\ (90°-\beta)$$

[0061] These top angle α and bottom angle β influence the direction in which each antenna principally radiates.

[0062] In a calculation assumption of having a 5G base station of 30m height and an antenna system 1 situated at 1.5m height, the bottom angle β varies from 75° (for a distance between the 5G base station and the antenna system 1 of 100m) to 88° (for a distance greater than

500m). Figure 7 illustrates the variation of the bottom angle β for each distance between the 5G base station and the antenna system 1.

[0063] A good compromise is obtained for a bottom angle β of 87°, that is a top angle α of 6°.

[0064] The vehicular antenna assembly 100 is designed to be operable as a massive multiband multiple input multiple output (MIMO) vehicular antenna having a beamforming solution.

[0065] To this end, the number of antennas 41, 42, 43 is greater than twenty. It is for instance comprised between 30 and 100.

[0066] This massive MIMO antenna array has a large number of steerable ports enabling beamforming, which means that radio signals and information can be sent directly to another device (for instance the 5G base station) instead of broadcasting everywhere. This has the added benefit of also reducing radio interference across the cell, resulting in a more enjoyable user experience.

[0067] The exact number of used antennas depends on the operating frequency of the antenna system 1 because the signal wavelength plays a role in the separation distance required between the antennas carried by the carrier. In this respect, the conductive layer 50 improves the electrical separation and the overall envelope correlation coefficient (ECC). In other words, the represented dielectric carriers 30; 130 can carry a greater number of antennas than a dielectric carrier lacking conductive layer 50.

[0068] The antennas carried by the carrier 30; 130 can be of various types. Here, they are all of the same type.

[0069] The type of the antennas can be, for instance, patch array (as shown in Figure 2), dipole array, slot antenna array or dielectric lens array.

[0070] Here, the patch array is obtained by metallization of the outer side face 31 of the dielectric carrier 30; 130. Feeding lines connecting the antennas to the printed circuit board 20; 130 are obtained in the same way. Feeding lines connecting the antennas to the ground conductive layer 50 may be obtained by drilling holes through the wall of the dielectric carrier 30; 130.

[0071] Consequently, the antennas are all electrically connected to the electronic components of the printed circuit board 20; 120 so as to be used as transmitter and/or receiver. The beamforming is carried out through electrical signal phase variation feeding the antennas.

[0072] The antennas are regularly distributed all around the dielectric carrier 30; 130, at several heights on this dielectric carrier 30, in order to obtain an omnidirectional antenna system 1.

[0073] In the example represented in Figure 2, the dielectric carrier 30 is fitted with large antennas 41, little antennas 43 and medium antennas 42.

[0074] Six large antennas 41 are regularly distributed all around the main axis A1, at a little height above the printed circuit board 20.

[0075] Eight medium antennas 42 are regularly distributed all around the main axis A1, at a medium height above the printed circuit board 20.

[0076] Twenty-four little antennas 42 are regularly distributed all around the main axis A1, at a great height above the printed circuit board 20 (next to the top extremity of the dielectric carrier).

[0077] The distance between the large antennas 41 and the bottom extremity of the dielectric carrier is greater than the distance between the little antennas 43 and the top extremity of the dielectric carrier. Consequently, the propagation of the waves emitted by these large antennas is not disturbed by the printed circuit board 20; 120.

[0078] In the shown embodiments, each antenna is composed of a single piece of metal having a squared shape (curved around the main axis A1). This piece of metal can be provided with resonance slot(s).

[0079] To ensure a good communication between the vehicle and the 5G base station, implementing the antenna system 1 in an overhead position is preferred. The best integration option is on the vehicle roof 101.

[0080] Thus, as shown in Figure 3, the finishing cover 60 has a shark-fin shape, with a base opened, and is provided with means for fixing it onto the roof 101 of the vehicle 100, all around the chassis 10, the printed circuit board 20 and the dielectric carrier 30 to protect them.

[0081] As explained above, the chassis 10 can be fixed above or under the roof 101. But in both embodiments, the upper part of the dielectric carrier 30; 130 is housed into the finishing cover 60, above the roof. On the contrary, the printed circuit board 20; 120 is situated between the roof 101 and the chassis 10; 110, that is to say under or above the roof.

[0082] As shown in Figures 2 and 4, in both embodiments, the 5G Massive MIMO antenna array can coexist with at least one other antenna, for instance a GNSS antenna, a satellite digital audio radio service antenna (SDARS), or a Bluetooth Low Energy antenna (BLE).

[0083] This other antenna is preferably situated at a distance from the dielectric carrier 30, 130, and is connected to the printed circuit board 20; 120.

Claims

1. Antenna system (1) to be mounted on a vehicle (100), comprising:

   - a chassis (10; 110),
   - a printed circuit board (20; 120) fixed to the chassis (10; 110) and defining a main plane (P1), and
   - a dielectric carrier (30; 130) that extends along a main axis (A1) perpendicular or tilted relative to said main plane (P1) and that has a side face (31) carrying several antennas (41, 42, 43) electrically connected to the printed circuit board (20; 120).

2. Antenna system according to claim 1, wherein the

dielectric carrier (30) is hollow and has an outer side face (31) carrying said several antennas (41, 42, 43) and an inner side face (32) at least partially coated with a conductive layer (50; 150).

3. Antenna system according to claim 2, wherein the conductive layer (50; 150) is electrically connected to a ground terminal of the printed circuit board (20; 120).

4. Antenna system according to any one of claims 2 and 3, wherein the dielectric carrier (30; 130) is directly fixed onto the printed circuit board (20) by means of its conductive layer (50; 150).

5. Antenna system according to any one of claims 1 to 4, wherein the dielectric carrier (30; 130) has an essentially rotationally symmetrical shape.

6. Antenna system according to claim 5, wherein at least a part of the dielectric carrier (30) carrying said several antennas (41, 42, 43) has a cylindrical shape.

7. Antenna system according to claim 5, wherein at least a part of the dielectric carrier (130) carrying said several antennas (41, 42, 43) has a conical shape, with a top angle preferably lying from 4 degrees to 30 degrees.

8. Antenna system according to any one of claims 1 to 7, wherein said antennas (41, 42, 43) are regularly distributed all around the dielectric carrier (30).

9. Antenna system according to any one of claims 1 to 8, wherein at least one of said antennas (41, 42, 43) has a size different from the size of another one of said antennas (41, 42, 43).

10. Antenna system according to claims 8 and 9, wherein first antennas (41) of same size are regularly distributed all around the dielectric carrier (30), at a first height relative to said printed circuit board (20; 120), and second antennas (42) of same size are regularly distributed all around the dielectric carrier (30), at a second height relative to said printed circuit board (20; 120) distinct from said first height, the size of said first antennas (41) being different from the size of said second antennas (42).

11. Antenna system according to any one of claims 1 to 10, comprising a finishing cover (60), said finishing cover (60) and said chassis (10; 110) encasing the dielectric carrier (30; 130).

12. Antenna system according to claim 11, wherein the finishing cover (60) has a shark-fin shape.

13. Antenna system according to any one of claims 1 to 12, comprising another antenna fixed to the printed circuit board (20; 120), at a distance from said dielectric carrier (30; 130).

14. Vehicle (100) comprising a roof (101), **characterized in that** it also comprises an antenna system (1) according to any one of the preceding claims, fixed to the roof (101) so that said dielectric carrier (30; 130) extends at least partially above the roof (101).

15. Vehicle (100) according to claim 14, wherein said chassis (10; 110) is located between said roof (101) and said printed circuit board (20; 120), above or below said roof (101).

Fig.1

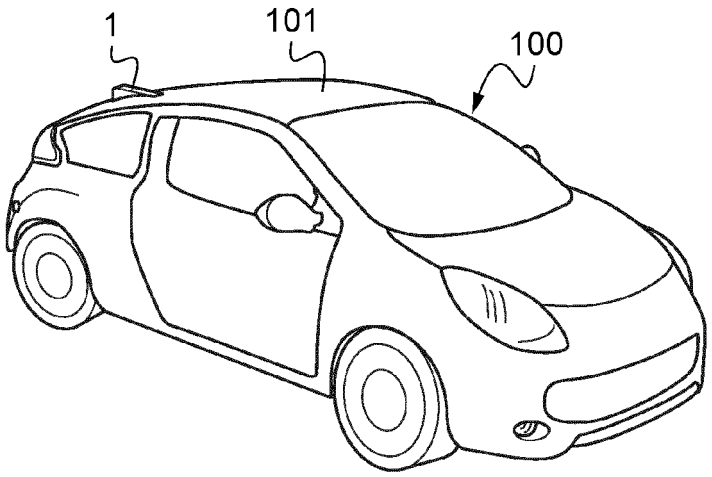


Fig.2

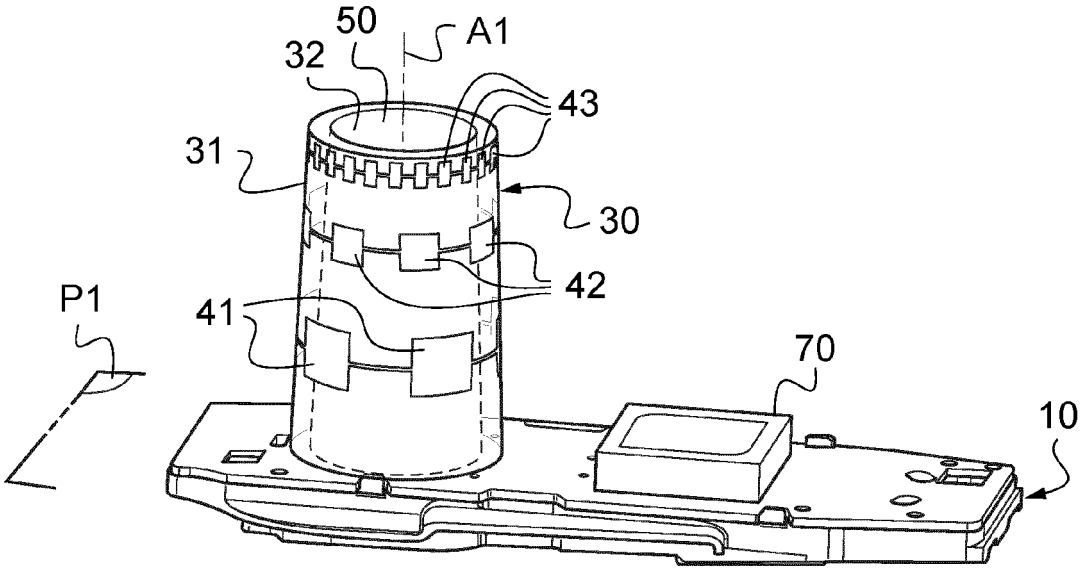
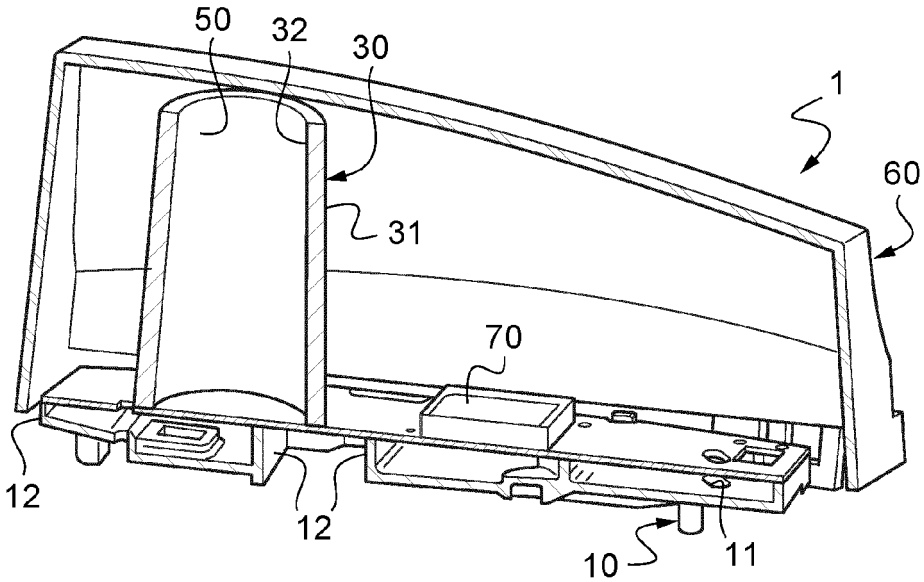


Fig.3



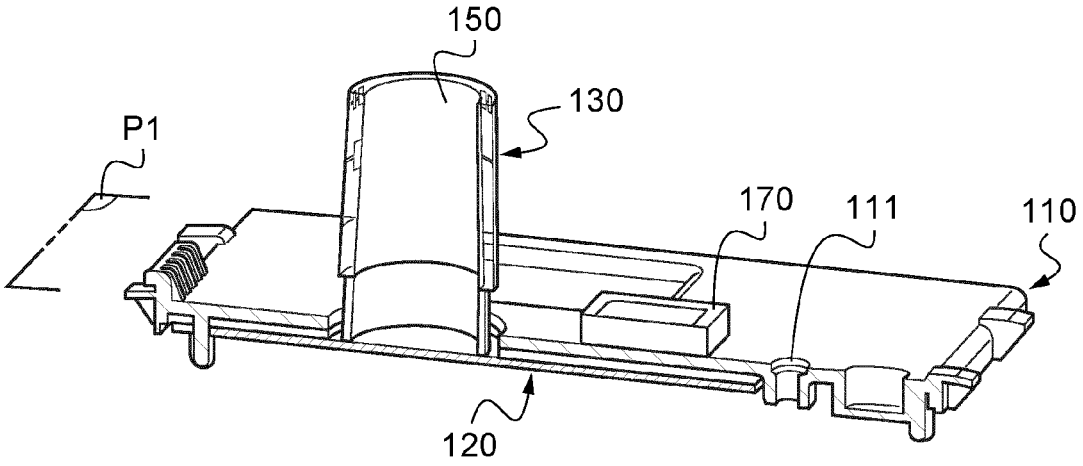


Fig.4

Fig.5

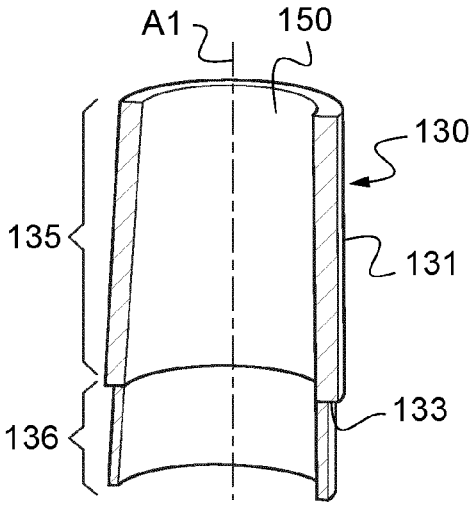


Fig.6

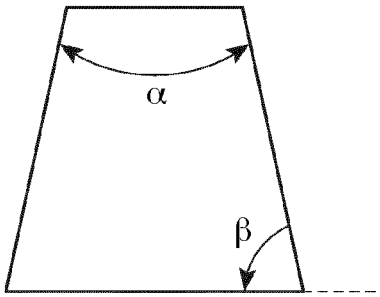
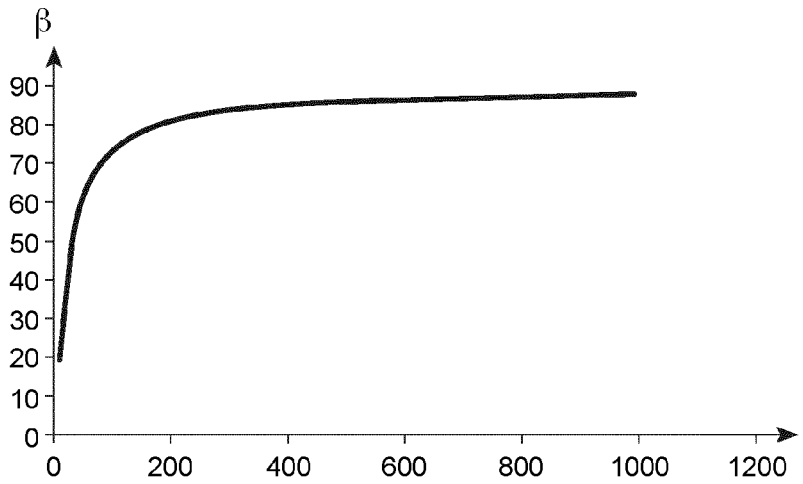


Fig.7



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EUROPEAN SEARCH REPORT

Application Number
EP 19 21 8179

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	JAECK VINCENT ET AL: "A Switched-Beam Conformal Array With a 3-D Beam Forming Capability in C-Band", IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 65, no. 6, 24 April 2017 (2017-04-24), pages 2950-2957, XP011651708, ISSN: 0018-926X, DOI: 10.1109/TAP.2017.2696418 [retrieved on 2017-06-02]	1-11	INV. H01Q1/32 H01Q1/38 H01Q1/42 H01Q21/20 H01Q21/28
A	* the whole document *	12-15	
X	JAECK V ET AL: "A Conical Patch Antenna Array for Agile Point-to-Point Communications in the 5.2-GHz Band", IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, IEEE, PISCATAWAY, NJ, US, vol. 15, 20 November 2015 (2015-11-20), pages 1230-1233, XP011605985, ISSN: 1536-1225, DOI: 10.1109/LAWP.2015.2502724 [retrieved on 2016-04-07]	1-11	TECHNICAL FIELDS SEARCHED (IPC) H01Q
A	* the whole document *	12-15	
X	WO 2019/221548 A1 (IM JU HYEON [KR]) 21 November 2019 (2019-11-21)	1-4,8-15	
A	* paragraph [0176] - paragraph [0218]; figures 10-13 *	5-7	
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A	* paragraph [0016] - paragraph [0032]; figures 1-5 *	9,10, 12-15	

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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	10 June 2020	Keyrouz, Shady

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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E : earlier patent document, but published on, or after the filing date
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L : document cited for other reasons

& : member of the same patent family, corresponding document

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EUROPEAN SEARCH REPORT

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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TECHNICAL FIELDS SEARCHED (IPC)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	10 June 2020	Keyrouz, Shady

CATEGORY OF CITED DOCUMENTS

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P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

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