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(54) **DIELECTRIC WAVEGUIDE CONNECTOR**

(57) A dielectric waveguide connector (100, 200) for guiding electromagnetic radiation between a high frequency radiating device and a dielectric waveguide (105, 205) comprising: a cone or pyramid structure (102, 202) provided from a dielectric material having a first dielectric permittivity ε_{r1}; an integrated circuit insert (103, 203) at the wide side of the cone or pyramid structure (102, 202) configured to house an integrated circuit (106, 206) having an antenna; a waveguide inset (101, 201) at the narrow side of the cone or pyramid structure (102, 202) configured to house a dielectric waveguide (105, 205); a dielectric lens (104, 204) provided from a dielectric material having a second relative permittivity ε_{r2} and wherein $\varepsilon_{r1} < \varepsilon_{r2}$; wherein the dielectric lens (104, 204) is arranged in the center of the cone or pyramid structure (102, 202) above the integrated circuit insert (103, 203).

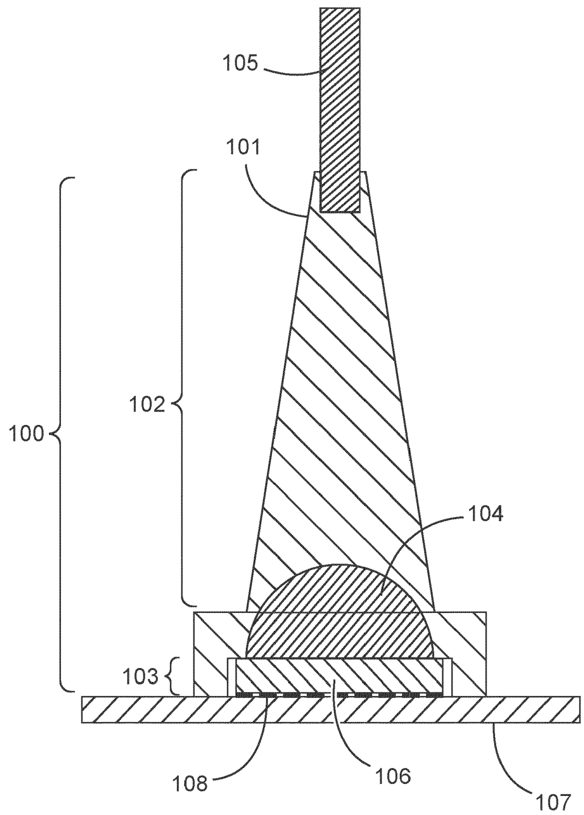

Fig. 3

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Description

TECHNICAL FIELD

[0001] The present invention relates to a dielectric waveguide connector for guiding electromagnetic radiation between a high frequency radiating device and a dielectric waveguide, a method for manufacturing such a dielectric waveguide connector, the use of a cone or pyramid structure in such a dielectric waveguide connector and a use of an integrated circuit in such a dielectric waveguide connector.

TECHNICAL BACKGROUND

[0002] High frequency transceiver devices are used in many application fields ranging from radar and sensing applications to communication applications. In many cases, it is required to connect a high frequency transceiver device to a remote antenna or to synchronize two remote high frequency transceiver devices to enable a coherent system or transmit information between one high frequency transmit device to a receiving device. In the prior art, this is usually provided by using metal transmission lines in form of coaxial lines or as metal tubes. This is, however, a bulky and very expensive solution. Additionally, the performance of metal transmission lines is not optimal because of the large damping especially at high frequencies above 100 GHz. Better performance can be obtained with dielectric waveguides for guiding mmW or Terahertz signals from one point to the other. A bottleneck for the use of dielectric waveguides is often the complicated coupling of the signal of high-frequency component to dielectric waveguide.

[0003] A dielectric waveguide is an element that can be used advantageously to transfer signals between high frequency transceiver devices or between high frequency transceiver devices and other high frequency components for example antennas. It comprises low-loss dielectric material and has usually the shape of round or rectangular strip with diameters of few millimeters or below one millimeter. Figure 1 shows such a conventional interconnect system. In this system the, coupling between a radiating chip and a dielectric waveguide 512 is indicated with reference 510. In this known example, the coupling between the radiating chip and the dielectric waveguide is provided by a beam steering antenna as it can be realized with a phased array to direct the beam exactly to the dielectric waveguide. However, this method is relatively complicated and expensive because complex antenna system and steering electronics is required to steer the beam flexibly to the optimum input point of the dielectric waveguide.

[0004] Traditionally, waveguides are used in systems of high frequency technology, which are designed either as a metallic waveguide or as coaxial cables. In the context of this application considered high-frequency signals with frequencies above 30 GHz and into the Terahertz range these waveguides are very expensive and also inflexible and bulky. Dielectric waveguides will therefore become more important if suitable coupling technologies are available. In known high-frequency components, different methods of coupling have hitherto been used. An interface for transmitting sub-millimeter waves between a semiconductor chip and a dielectric waveguide is described, for example, in US 2012/0068891 A1 and US 9,484,630 B2. A coupling between the semiconductor chip and the dielectric waveguide takes place here via a directional antenna arranged on an upper side of the semiconductor chip. By means of beam steering methods, the directional antenna can direct the radio frequency beam to the waveguide disposed above so that radio frequency energy is effectively coupled into the waveguide.

[0005] Another solution is described in the publication of Martin Geiger, Martin Hitzler, Johannes Iberle, Christian Waldschmidt: "A Dielectric Lens Antenna Fed by a Flexible Dielectric Waveguide At 160 GHz", EuCAP Conference 2017. Here the high-frequency signal from the chip is connected via a bond wire to a printed circuit board and led to a special waveguide component with coupler. This coupler couples the signal from metallic waveguide into a dielectric waveguide.

[0006] A summary of technical solutions and applications of dielectric waveguides is presented in "Innovations in Terahertz Interconnects; High-Speed Data Transport Over Fully Electrical Terahertz Waveguide Links" and in "Polymer Microwave Fibers; A New Approach That Blends Wireline, Optical, and Wireless Communication" both papers in IEEE Microwave Magazine, January 2020, pp. 35-66.

[0007] In view of this, it is found that a further need exists to provide a more simple and more cost-effective coupling element.

SUMMARY

[0008] In the view of the above, it is an object of the present invention to provide a simple and cost-effective coupling element and to achieve an efficient and cost-effective coupling between high frequency transceiver devices and dielectric waveguides.

[0009] These and other objects, which become apparent upon reading the following description, are solved by the subject matter of the independent claims. The dependent claims refer to preferred embodiments of the invention.

[0010] The present invention sets itself over the above mentioned prior art, the task of specifying a high-frequency component with a high frequency device to waveguide coupling for high-frequency signals above 30 GHz and up to the terahertz range, which is less lossy and which can be fabricated with low cost.

[0011] A first aspect of the present invention relates to a dielectric waveguide connector for guiding electromagnetic radiation between a high frequency radiating device and a dielectric waveguide comprising: a cone or pyramid structure provided from a dielectric material having a first dielectric permittivity ε_{r1}; an integrated circuit insert at the wide side of the pyramid structure configured to house an integrated circuit having an antenna; a waveguide inset at the narrow side of the pyramid structure (102) configured to house a dielectric waveguide; a dielectric lens provided from a dielectric material having a second relative permittivity ε_{r2} and wherein $\varepsilon_{r1} < \varepsilon_{r2}$; wherein the dielectric lens is arranged in the center of the pyramid structure above the integrated circuit insert. The dielectric lens preferably has the shape of a half sphere with a flat surface at the side directing to integrated circuit insert. However, the dielectric lens also can have an ellipsoid shape or a hyper hemisphere shape.

[0012] The dielectric waveguide comprises a waveguiding dielectric material in the solid state capable of conducting the incoming or outgoing RF electromagnetic signals along a longitudinal extent of the dielectric waveguide.

[0013] Preferably, the pyramid structure has a step pyramid shape. In this context, it should be noted that the term "pyramid" is to be understood in a broad sense and includes all suitable geometries to provide an intended wave guiding having a "broader" base geometry and "smaller" tip geometry. Moreover, the present invention also comprises inclined pyramids and inclined cones, in particular bent geometries in which deflection mirrors are used.

[0014] It is further preferred that the dielectric waveguide is glued into the waveguide inset. Furthermore, it is preferred that the waveguide connector comprises locking means configured to lock the waveguide connector over the integrated circuit in such a way that a close contact of the integrated circuit to the dielectric lens is provided.

[0015] Preferably, the waveguide insert is configured such that the dielectric waveguide can be stuck into the waveguide inset providing a detachable connection, wherein the clear width of the waveguide insert preferably decreases towards the inside of the waveguide insert.

[0016] The dielectric lens is preferably provided from Silicon. In this respect it is further preferred that the dielectric lens is provided from a monocrystalline, high ohmic Silicon. In an alternative, the dielectric lens is provided from a plastic material with high permittivity or an aluminum nitride.

[0017] A second aspect of the present invention relates to a method for manufacturing such a dielectric waveguide connector, comprising the step of printing the dielectric waveguide connector by means of a 3D-printing method using plastic materials of different dielectric constants with the relationship $\varepsilon_{r1} < \varepsilon_{r2}$.

[0018] In a further aspect of the present invention, such a dielectric waveguide connector is manufactured comprising the steps of printing the dielectric waveguide connector except the dielectric lens by means of a 3D-printing method using plastic material having a dielectric constant ε_{r1} and inserting a separate dielectric lens having a dielectric constant ε_{r2} by snapping-in.

[0019] In a further aspect of the present invention, such a dielectric waveguide connector is manufactured comprising the steps of injection molding the dielectric waveguide connector except the dielectric lens using plastic material having a dielectric constant ε_{r1} and inserting a separate dielectric lens having a dielectric constant ε_{r2} by snapping-in or by gluing.

[0020] In a further aspect of the present invention, such a dielectric waveguide connector is manufactured comprising the steps of injection molding the dielectric waveguide connector using plastic material having a dielectric constant ε_{r1} and placing a separate dielectric lens provided from a material having a dielectric constant ε_{r2} a molding tool before the plastic material is injected into the molding tool.

[0021] A further aspect of the present invention relates to a use of a cone or pyramid structure provided from a dielectric material in such a dielectric waveguide connector explained above.

[0022] Finally, a further aspect of the present invention relates to a use of an integrated circuit having an antenna in such a dielectric waveguide connector explained above.

BRIEF DESCRIPTION OF DRAWINGS

[0023] In the following, the invention is described exemplarily with reference to the enclosed figure, in which

Figure 1 is a schematic view of prior art coupling of a radiating chip to a dielectric waveguide;

Figure 2 is a schematic view of a dielectric waveguide connector together with printed circuit board and a dielectric waveguide according to a first preferred embodiment of the present invention;

Figure 3 is a schematic cross-section view of the dielectric waveguide connector shown in figure 1;

Figure 4 is a schematic view of a dielectric waveguide connector together with printed circuit board and a dielectric waveguide according to a second preferred embodiment of the present invention;

Figure 5 is a schematic cross-section view of the dielectric waveguide connector shown in figure 4; and

Figure 6 is a schematic cross-section view of a dielectric waveguide connector together with printed circuit board and a dielectric waveguide according to a third preferred embodiment of the present invention;

[0024] Notably, the figures are merely schematic representations and serve only to illustrate embodiments of the invention. Identical or equivalent elements are in principle provided with the same reference signs.

DESCRIPTION OF EMBODIMENTS

[0025] Figure 2 shows a perspective view of a dielectric waveguide connector 100. The dielectric waveguide connector 100 consists mainly of two types of dielectric materials, for example a non-conducting plastic material with one type of high dielectric permittivity and the other type of low dielectric permittivity. Both types have low damping factor for high-frequency waves.

[0026] The dielectric waveguide connector 100 comprises/has four main components: A waveguide insert 101, a pyramid structure 102, an integrated circuit insert 103, and a dielectric lens 104. The measures of the waveguide insert 101 are chosen so that it fits to a cross-section of the dielectric waveguide 105, e.g. it can be a rectangular cavity in the upper part of the pyramid structure 102. It has the task to comprise and fix the dielectric waveguide 105 to be connected. The dielectric constant of the pyramid structure 102 should be the same or similar as that of the dielectric waveguide 105 to prevent reflection losses.

[0027] The dielectric constant of the material of the pyramid structure 102 has a first relative permittivity ε_{r1} in the range from 2 to 6. The dielectric Lens 104 is made from or consists of dielectric material with a relative permittivity ε_{r2} with a ratio of relative permittivities $\varepsilon_{r1} < \varepsilon_{r2}$. The dielectric Lens 104 can be made of Silicon with $\varepsilon_{r2} = 12$ or of any other dielectric material with high permittivity.

[0028] The minimum measure of the cross-section of dielectric waveguide results from dielectric material ε_r and wavelength within this material determined from operational frequency.

[0029] The lower end of the dielectric waveguide connector 100 shown in figure 2 comprises an integrated circuit insert 103 with a dielectric lens 104 directly above the integrated circuit insert 103. The integrated circuit 106 with an integrated antenna (antenna in package or antenna on chip) can transmit or receive electromagnetic waves. The electromagnetic waves can permeate the dielectric packaging material of the integrated circuit package, if any. Directly above the integrated circuit 106, the dielectric lens 104 is located. Because of radiation from integrated circuit 106 in upward direction, the radiation passes the dielectric lens 104 and will be focused towards the pyramid structure 102. The tighter form of pyramid structure 102 focusses further the radiated beam towards the waveguide insert 101 and ensures the effective transition towards the dielectric waveguide 105. The stronger the focusing action of the dielectric lens 104 performs, the shorter can be the pyramid structure 102.

[0030] Figure 3 shows a cross-sectional view of the dielectric waveguide connector 100. Similar to the elements shown in figure 2, there is a printed circuit board 107 whereupon the integrated circuit 106 and the dielectric waveguide connector 100 are attached. As shown, the integrated circuit 106 and the dielectric lens 104 are in close contact. The integrated circuit 106 is soldered to the conducting lines of the printed circuit board 107 by contact pads 108 thereby providing electrical connection. The QFN package can measure 5 x 5 x 0.8 mm^3 for example.

[0031] The integrated circuit 106 can for example be a standard QFN-package with a radar transceiver chip inside. The radar transceiver chip has an integrated antenna or an antenna in package.

[0032] A step-wise tightening of the pyramid structure 102 can help to focus the radiated beam more efficiently towards the dielectric waveguide 105. The physical process of this transition is called multimode interference or self-imaging principle (cf. e.g. L. B. Soldano and E. C. M. Pennings, "Optical Multi-Mode Interference Devices Based on Self-Imaging: Principles and Applications," Journal of Lightwave Technology, vol. 13, no. 4, pp. 615-627, 1995).

[0033] Figure 4 shows a perspective view of dielectric waveguide connector 100 with a step pyramid shape. The dielectric waveguide connector 100 consists mainly of two types of dielectric material, for example a non-conducting plastic with one type of high dielectric permittivity and the other type of low dielectric permittivity. Both types have low damping factor for high-frequency waves.

[0034] Also here, the dielectric waveguide connector 100 has four main components: A waveguide insert 101, a pyramid structure 102a with a step pyramid shape, an integrated circuit 103, and a dielectric lens 104. The measures of waveguide insert 101 is chosen so that it fits to a cross-section of the dielectric waveguide 105, e.g. it can be a rectangular cavity in the upper part of the pyramid structure 102. It has the task to house/comprise and fix the dielectric waveguide 105 to be connected. The dielectric constant of the pyramid structure 102 should be the same or similar as that of the dielectric waveguide 105 to prevent reflection losses.

[0035] The dielectric constant of the material of pyramid structure 102 has a first relative permittivity ε_{r1} in the range from 2 to 6. The dielectric Lens 104 consists of dielectric material with relative permittivity ε_{r2} with a ratio of relative permittivities $\varepsilon_{r1} < \varepsilon_{r2}$.

[0036] The minimum measure of the cross-section of dielectric waveguide 105 results from dielectric material ε_r and wavelength within this material determined from operational frequency.

[0037] The lower end of the dielectric waveguide connector 100 in figure 4 comprises a cavity in form of an integrated circuit insert 103 with a dielectric lens 104 directly above the integrated circuit insert 103. Directly below the dielectric lens 104 is the radiating integrated circuit 106. Because of the radiation from the integrated circuit 106 in upward direction, the radiation passes the dielectric lens 104 and will be focused towards the pyramid structure 102. The step form of pyramid structure 102 focusses further the radiated beam towards the waveguide insert 101 and ensures the effective transition towards the dielectric waveguide 105. Every step of pyramid structure 102 acts as a mode converter and causes further focusing until fundamental mode of the dielectric waveguide 105.

[0038] Figure 5 shows a cross-sectional view of a dielectric waveguide connector 100 with step pyramid shape. Additional to the elements shown in figure 4, there is a printed circuit board 107 whereupon the integrated circuit 106 and the dielectric waveguide connector 100 are attached. As shown, the integrated circuit 106 and the dielectric lens 104 are in close contact. The integrated circuit 106 is soldered to the conducting lines of printed circuit board 107 by contact pads 108 thereby providing electrical connection.

[0039] Figure 6 shows a cross-sectional view of a dielectric waveguide connector 200 according to a further preferred embodiment of the present invention. The dielectric waveguide connector 200 comprises an internal beam deflection to redirect the beam into the desired direction. In the embodiment shown in figure 6, the beam is deflected parallel to the printed circuit board 107, which is advantageous for some applications. For this purpose, a bent pyramid structure 202 with a mirror area 209 is used. With respect to the functions of the respective parts, it is referred to the above explanations.

[0040] There is a printed circuit board 207 whereupon an integrated circuit 206 and the dielectric waveguide connector 200 are attached. As shown, also here, the integrated circuit 206 and the dielectric lens 204 are in close contact. The integrated circuit 206 is soldered to the conducting lines of the printed circuit board 207 thereby providing electrical connection to the other radar electronics. The dielectric waveguide 205 is inserted into a waveguide insert 201 horizontally. This has advantage of reduced height of the dielectric waveguide connector 200 and saves place in y-direction.

[0041] In particular, there are a total of 3 uses for the dialectical waveguide connector 100. First, both sides of the dialectical waveguide connector 100 are firmly connected with glue (for example) for permanent connection to integrated circuit 106 at the one side and to dielectric waveguide 105 at the other side. Second, the broad side of the pyramid-shaped connector is firmly connected to the printed circuit board 107 and/or the integrated circuit 106. Third, the dielectric waveguide 105 is firmly connected to the dialectical waveguide connector 100 and the broad side can be detachably attached to the integrated circuit 106.

[0042] Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from the study of the drawings, the disclosure, and the appended claims. In the claims the word "comprising" does not exclude other elements or steps and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope of the claims.

LIST OF REFERENCE SIGNS

[0043]

100	dielectric waveguide connector
101	waveguide insert
102	pyramid structure
103	integrated circuit insert
104	dielectric lens
105	dielectric waveguide
106	integrated circuit
107	printed circuit board
108	contact pads
200	dielectric waveguide connector
201	waveguide insert
202	pyramid structure
203	integrated circuit insert
204	dielectric lens
205	dielectric waveguide
206	integrated circuit
207	printed circuit board
208	contact pads
209	mirror area

Claims

1. A dielectric waveguide connector (100, 200) for guiding electromagnetic radiation between a high frequency radiating device and a dielectric waveguide (105, 205) comprising:

a cone or pyramid structure (102, 202) provided from a dielectric material having a first dielectric permittivity ε_{r1};
an integrated circuit insert (103, 203) at the wide side of the cone or pyramid structure (102, 202) configured to house an integrated circuit (106, 206) having an antenna;
a waveguide inset (101, 201) at the narrow side of the cone or pyramid structure (102, 202) configured to house a dielectric waveguide (105, 205);
a dielectric lens (104, 204) provided from a dielectric material having a second relative permittivity ε_{r2} and wherein $\varepsilon_{r1} < \varepsilon_{r2}$; wherein
the dielectric lens (104, 204) is arranged in the center of the cone or pyramid structure (102, 202) above the integrated circuit insert (103, 203).

2. Dielectric waveguide connector (100) according to claim 1, wherein the cone or pyramid structure (102, 202) has a step cone shape or a step pyramid shape.

3. Dielectric waveguide connector (100, 200) according to claim 1 or claim 2, wherein the cone or pyramid structure (102, 202) is a bent structure (202) comprising at least one mirror area (209).

4. Dielectric waveguide connector (100) according to any one of the preceding claims, wherein the dielectric waveguide (105, 205) is glued into the waveguide inset (101, 201).

5. Dielectric waveguide connector (100, 200) according to any one of the preceding claims, wherein the waveguide connector (100, 200) comprises locking means configured to lock the waveguide connector (100, 200) over the integrated circuit (106, 206) in such a way that a close contact of the integrated circuit (106, 206) to the dielectric lens (104, 204) is provided.

6. Dielectric waveguide connector (100, 200) according to any one of the preceding claims, wherein the waveguide insert (101, 201) is configured such that the dielectric waveguide (105, 205) can be stuck into the waveguide inset (101, 201) providing a detachable connection, wherein the clear width of the waveguide insert (101, 201) preferably decreases towards the inside of the waveguide insert (101, 201).

7. Dielectric waveguide connector (100, 200) according to any one of the preceding claims, wherein the dielectric lens (104, 204) is provided from Silicon.

8. Dielectric waveguide connector (100, 200) according to any one of the preceding claims, wherein the dielectric lens (104, 204) is provided from a monocrystalline, high ohmic Silicon.

9. Dielectric waveguide connector (100, 200) according to any one of the claims 1 to 7, wherein the dielectric lens (1004, 204) is provided from aluminum nitride, or a plastic material with high permittivity.

10. Method for manufacturing a dielectric waveguide connector (100, 200) according to any one of claims 1 to 9, comprising the step of printing the dielectric waveguide connector (100, 200) by means of a 3D-printing method using plastic materials of different dielectric constants with the relationship $\varepsilon_{r1} < \varepsilon_{r2}$.

11. Method for manufacturing a dielectric waveguide connector (100, 200) according to any one of claims 1 to 9, comprising the step of printing the dielectric waveguide connector (100, 200) except the dielectric lens (104, 204) by means of a 3D-printing method using plastic material having a dielectric constant ε_{r1} and inserting a separate dielectric lens (104, 204) having a dielectric constant ε_{r2} by snapping-in.

12. Method for manufacturing a dielectric waveguide connector (100, 200) according to any one of claims 1 to 9, comprising the step of injection molding the dielectric waveguide connector (100, 200) except the dielectric lens (104, 204) using plastic material having a dielectric constant ε_{r1} and inserting a separate dielectric lens (104, 204) having a dielectric constant ε_{r2} by snapping-in.

13. Method for manufacturing a dielectric waveguide connector (100, 200) according to any one of claims 1 to 9, comprising the step of injection molding the dielectric waveguide connector (100, 200) using plastic material having a dielectric constant ε_1 and placing a separate dielectric lens (104, 204) provided from a material having a dielectric constant ε_{r2} a molding tool before the plastic material is injected into the molding tool.

14. Use of a cone or pyramid structure (102, 202) provided from a dielectric material in a dielectric waveguide connector (100, 200) according to any one of claims 1 to 9 and/or use of an integrated circuit (106, 206) having an antenna in a dielectric waveguide connector (100, 200) according to any one of claims 1 to 9.

15. Use of a dialectical waveguide connector (100, 200) which is permanently connected to an integrated circuit (106, 206) at one side and permanently connected to a dielectric waveguide (105, 205) at the other side; or permanently connected to an integrated circuit (106, 206) at one side and detachably connected to a dielectric waveguide (105, 205) at the other side; or detachably connected to an integrated circuit (106, 206) at one side and permanently connected to a dielectric waveguide (105, 205) at the other side.

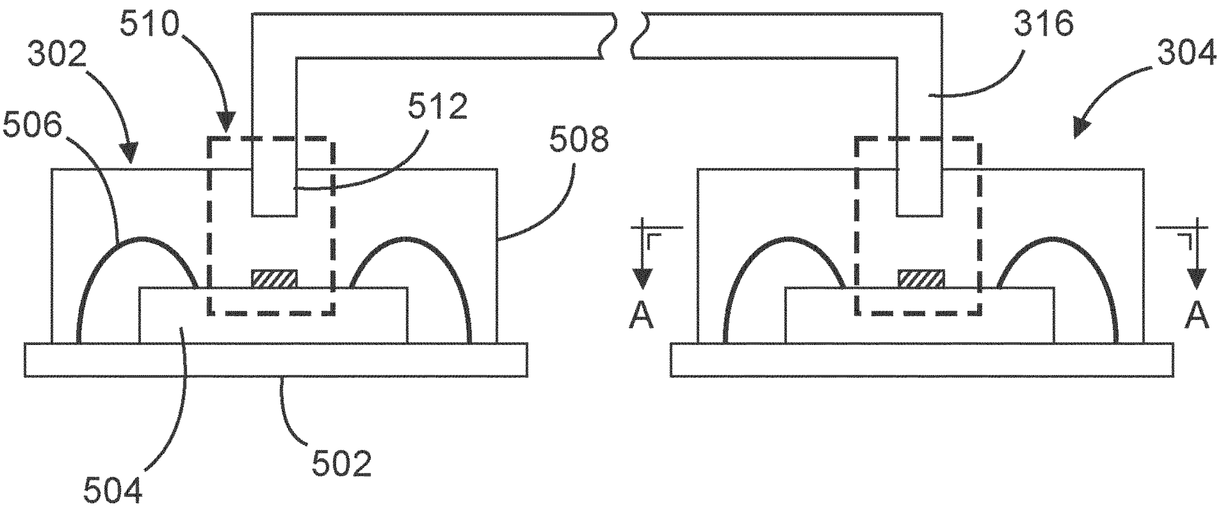

Fig. 1 (Prior Art)

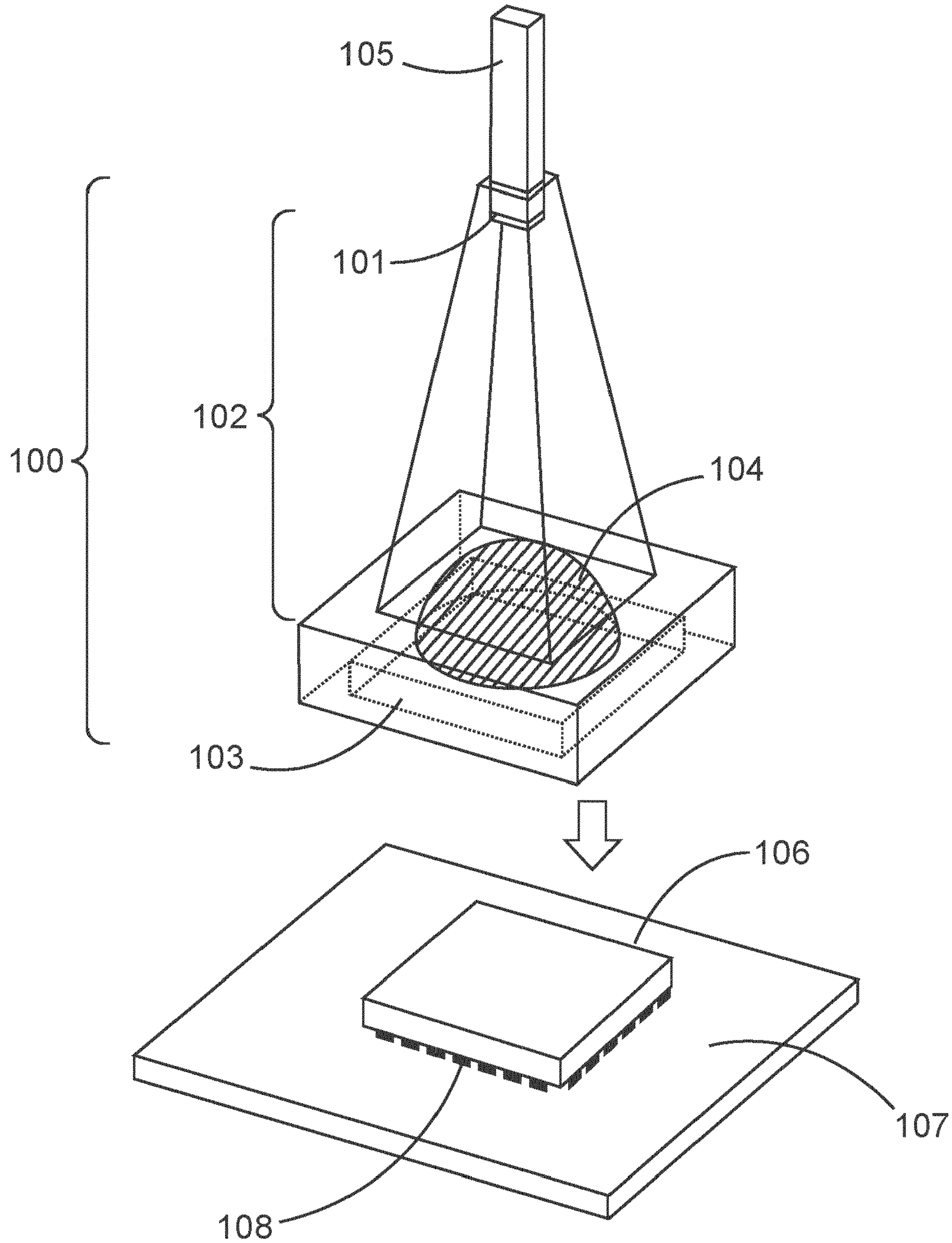

Fig. 2

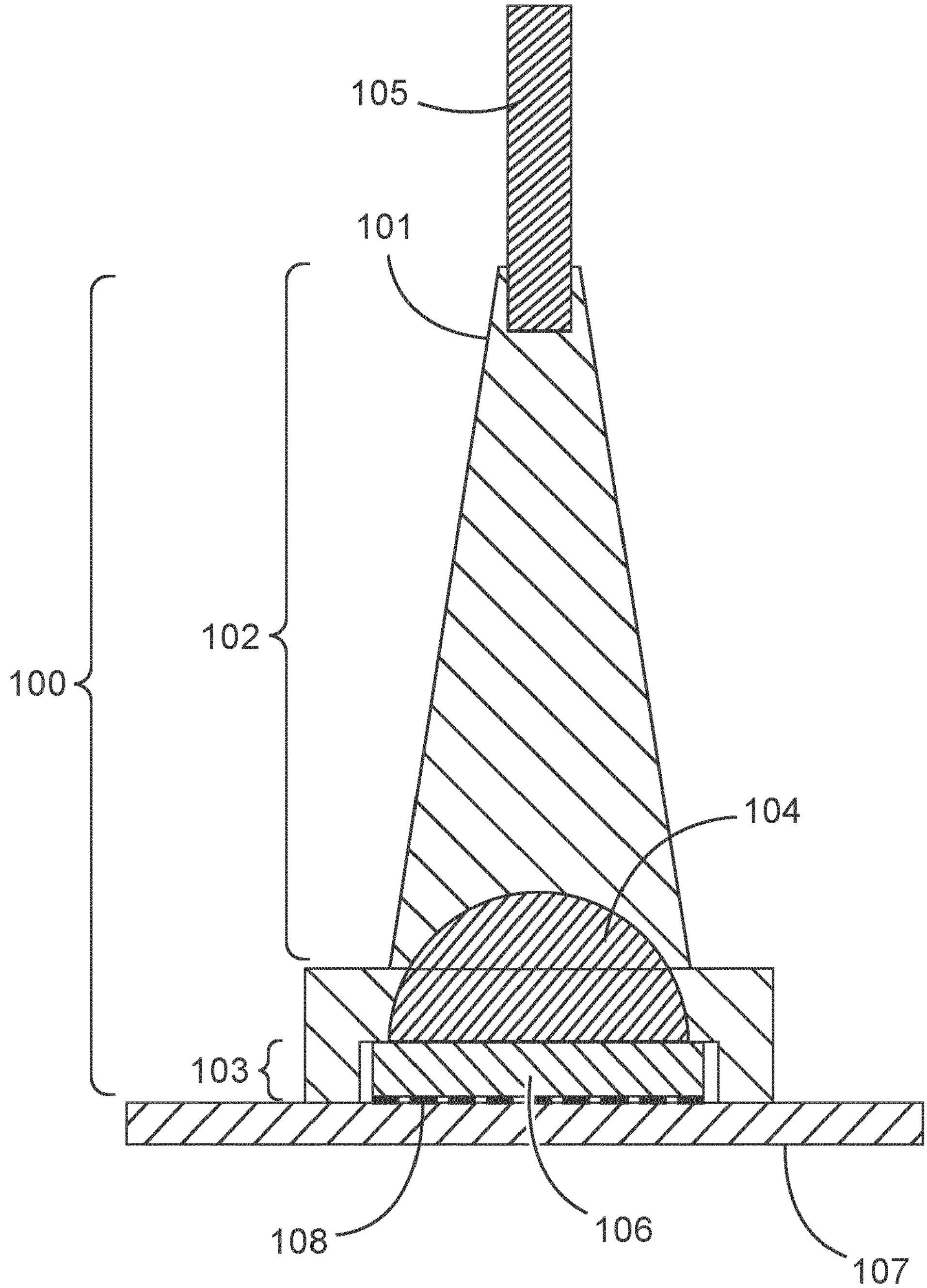

Fig. 3

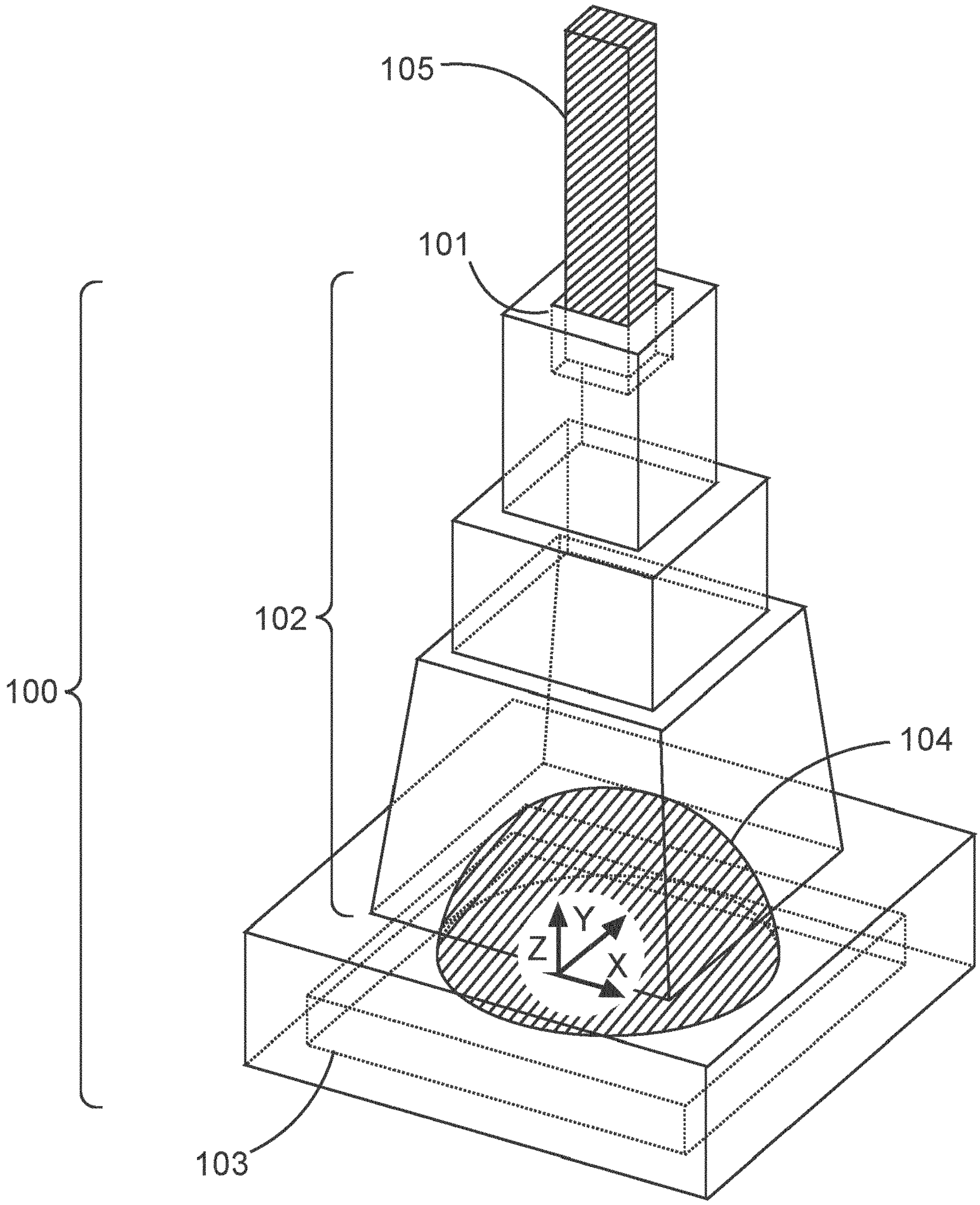

Fig. 4

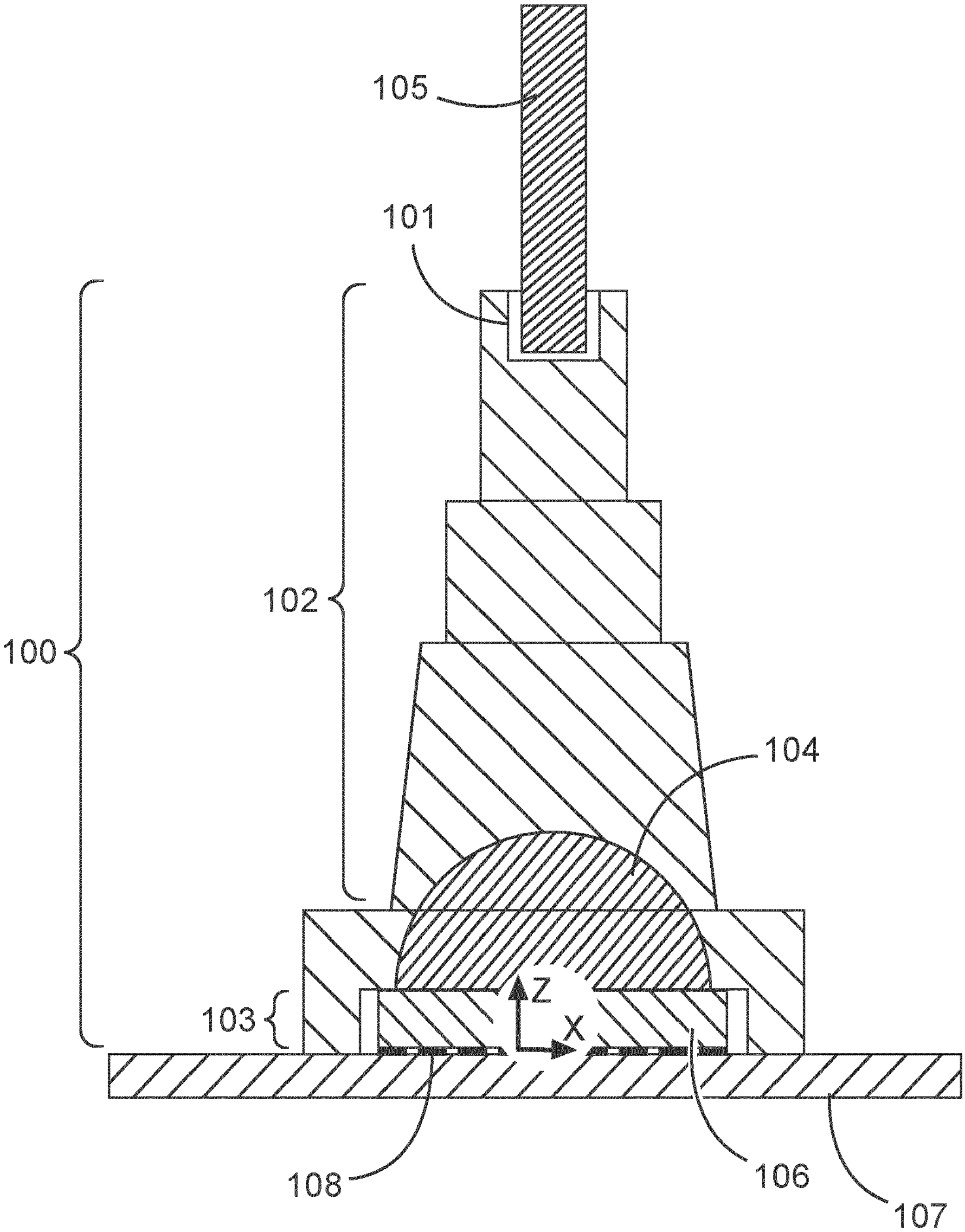

Fig. 5

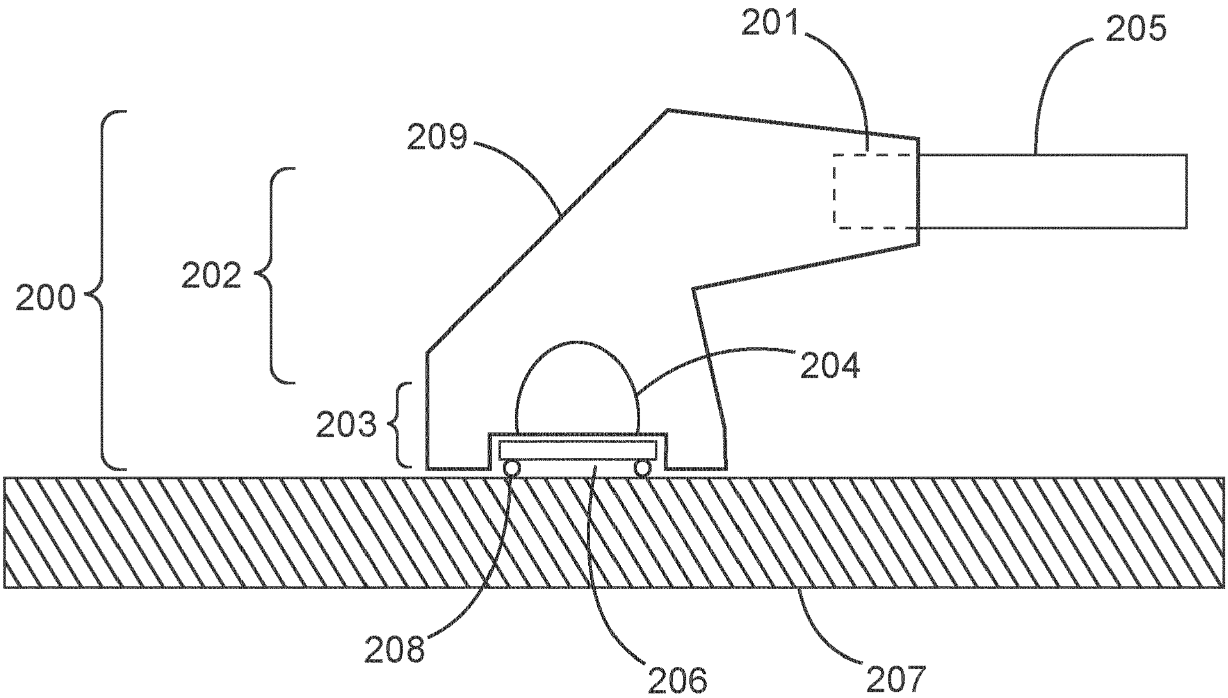

Fig. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 20 16 0101

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y,D A	US 9 484 630 B2 (TEXAS INSTRUMENTS INC [US]) 1 November 2016 (2016-11-01) * column 4, line 64 - column 5, line 30; figures 5, 6 *	1,2,4-15 3	INV. H01P5/08 ADD. H01Q1/22 H01Q19/08
Y A	US 2013/278360 A1 (KIM YANGHYO [US] ET AL) 24 October 2013 (2013-10-24) * page 5, paragraph 65 - page 6, paragraph 74; figures 6-9 *	1,2,4-15 3	
A	HOEL KARINA V ET AL: "3-D Printed Monolithic GRIN Dielectric-Loaded Double-Ridged Horn Antennas", IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 68, no. 1, 1 January 2020 (2020-01-01), pages 533-539, XP011764650, ISSN: 0018-926X, DOI: 10.1109/TAP.2019.2938563 [retrieved on 2020-01-02] * section III.A.; page 536 - page 537 *	1,10,11, 14,15	
A	WO 90/13927 A1 (UNIV LANCASTER [GB]) 15 November 1990 (1990-11-15) * page 3, line 21 - page 3, line 26; figure 1 * * page 6, line 34 - page 6, line 35; figure 2 *	1,12,14, 15	
A	JP H06 6128 A (MURATA MANUFACTURING CO) 14 January 1994 (1994-01-14) * page 3, paragraph 12 - page 3, paragraph 15; figure 1 *	1,13-15	
	-/--		

TECHNICAL FIELDS SEARCHED (IPC)
H01P
H01Q

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	4 August 2020	Blech, Marcel

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CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EUROPEAN SEARCH REPORT

Application Number
EP 20 16 0101

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 2019/109362 A1 (HAROUN BAHER [US] ET AL) 11 April 2019 (2019-04-11) * figure 1 * -----	5,6	
A	US 2020/021002 A1 (WOJNOWSKI MACIEJ [DE] ET AL) 16 January 2020 (2020-01-16) * page 2, paragraph 33 - page 3, paragraph 36; figure 4A * -----	3	
A	US 3 414 903 A (BARTLETT HOMER E ET AL) 3 December 1968 (1968-12-03) * column 2, line 32 - column 3, line 59; figure 2 * -----	1,14,15	

TECHNICAL FIELDS SEARCHED (IPC)

2

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	4 August 2020	Blech, Marcel

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04-08-2020

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 9484630 B2	01-11-2016	US 2012068891 A1 US 2015280320 A1	22-03-2012 01-10-2015
US 2013278360 A1	24-10-2013	NONE	
WO 9013927 A1	15-11-1990	AU 5554690 A WO 9013927 A1	29-11-1990 15-11-1990
JP H066128 A	14-01-1994	NONE	
US 2019109362 A1	11-04-2019	CN 111213282 A EP 3695457 A1 US 2019109362 A1 WO 2019075026 A1	29-05-2020 19-08-2020 11-04-2019 18-04-2019
US 2020021002 A1	16-01-2020	CN 110718540 A DE 102019118691 A1 US 2020021002 A1	21-01-2020 16-01-2020 16-01-2020
US 3414903 A	03-12-1968	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 20120068891 A1 **[0004]**
- US 9484630 B2 **[0004]**

Non-patent literature cited in the description

- Innovations in Terahertz Interconnects; High-Speed Data Transport Over Fully Electrical Terahertz Waveguide Links'' and in ''Polymer Microwave Fibers; A New Approach That Blends Wireline, Optical, and Wireless Communication. *IEEE Microwave Magazine,* January 2020, 35-66 **[0006]**
- **L. B. SOLDANO ; E. C. M. PENNINGS.** Optical Multi-Mode Interference Devices Based on Self-Imaging: Principles and Applications. *Journal of Lightwave Technology,* 1995, vol. 13 (4), 615-627 **[0032]**