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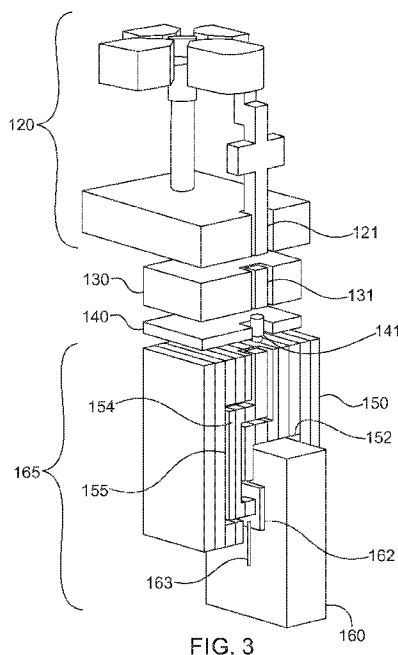
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(54) Title: MICROWAVE/MILLIMETER-WAVE WAVEGUIDE TO CIRCUIT BOARD CONNECTOR



(57) Abstract: Circuit board connector that provides electrical connection between conductive traces in a printed circuit board and microwave/millimeter-wave components. The circuit board connectors include an air spaced coaxial waveguide connecting to a trace on the circuit board. The circuit board connector is edge mounted on the circuit board. The connector includes a stiffener sheet with feedthrough and may be formed by depositing and patterning dielectric layers with metal layers.

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MICROWAVE/MILLIMETER-WAVE WAVEGUIDE TO CIRCUIT BOARD CONNECTOR

Related Applications

[0001] This application claims the benefit of priority of U.S. Provisional Application No. 62/662,382, filed on April 25, 2018, the entire contents of which application(s) are incorporated herein by reference.

Field of the Invention

[0002] The present invention relates generally to circuit board connections, and more particularly but not exclusively to connectors which may be removably attached to microwave/millimeter-wave components, such as antenna arrays or RF modules, while providing electrical connection between the circuit board and the microwave/millimeter-wave systems.

Background of the Invention

[0003] Applicant has recognized that there is no convenient way to removably attach a printed circuit board to microwave and millimeter-wave components, and that removable attachment of the printed circuit board, which may include driving electronics for an antenna, can provide advantages in future servicing or upgrading of the microwave/millimeter-wave-circuit board system. Accordingly, it would be an advance in the art to provide structures which allow a printed circuit board to be removably attached to microwave and millimeter-wave components, such as an antenna array. Furthermore, interconnections become increasingly challenging as the number of connections and the operating frequency increases, because the pitch between connections reduces.

Summary of the Invention

[0004] In one of its aspects the present invention may provide a circuit board connector that provides electrical connection between conductive traces in a printed circuit board and microwave/millimeter-wave structures which may include a coaxial waveguide. As such, circuit board connectors of the present invention may provide an electrical transition between the conductive traces of the printed circuit board and one or more coaxial waveguide structures disposed in the connector. The connector (and/or

microwave/millimeter-wave structures) may be monolithically fabricated via PolyStrata[®] multilayer build processing/technology, in which multiple layers of a material, such as a metal, are sequentially deposited to provide a unitary monolithic structure comprised of the sequential layers. Examples of PolyStrata[®] processing/technology are illustrated in U.S. Patent Nos. 7948335, 7405638, 7148772, 7012489, 7649432, 7656256, 7755174, 7898356 and/or U.S. Application Pub. Nos. 2010/0109819, 2011/0210807, 2010/0296252, 2011/0273241, 2011/0123783, 2011/0181376, 2011/0181377, and commonly owned copending application 62/614,636, each of which is incorporated herein by reference in their entirety (hereinafter the “incorporated PolyStrata[®] art”). As used herein, the mark “PolyStrata[®]” is used in conjunction with the structures made by, or methods detailed in, any of the incorporated PolyStrata[®] art.

[0005] The connector of the present invention may be soldered to the circuit board and may be configured to be removably attached to microwave/millimeter-wave structures to permit removable connection between the microwave/millimeter-wave structures and the combined circuit board/connector. (As used herein the terms “removable” and “removably attached” are defined to mean that parts may be reversibly joined and separated, without damage, by application of only a mechanical force; therefore, such terms exclude attachment by non-removable means, such as epoxy, or by means which require more than a mechanical force, such as solder, which required the application of heat.)

[0006] Accordingly, in one of its aspects, the present invention may provide a connector configured to provide physical and electrical connection to a circuit board having conductive traces. The connector may include a mounting feature for receiving an edge of the circuit board, and at least one coaxial waveguide disposed within the connector. The waveguide may include a center conductor having a first end, with the first end configured to be electrically connected to a conductive trace of the circuit board. The connector may include a plurality of sequential layers of a metal joined to provide a unitary monolithic structure, and the plurality of layers may be disposed perpendicular to a longitudinal axis of the center conductor. Alternatively, the plurality of layers may be disposed parallel to a longitudinal axis of the center conductor. The

at least one coaxial waveguide may include an air spaced coaxial waveguide, and the mounting feature may be a slot.

[0007] In a further of its aspects, the present invention may provide an antenna system comprising an antenna array; a connector in accordance with the present invention as described herein, with the center conductor thereof electrically connected to the antenna array; and at least one circuit board disposed in a mounting feature of the connector. The circuit board may be electrically connected to the center conductor of the connector to provide electrical connection between the circuit board and the antenna array. The circuit board may also include electronics for driving the antenna array. The antenna array may be removably attached to the connector, and may include a plurality of sequential layers of a metal joined to provide a unitary monolithic structure. The antenna array may also include a feedthrough electrically connected to the center conductor of the connector. The first end of the center conductor of the connector may be electrically connected to a selected electrical trace of the circuit board, and may be soldered thereto. In addition, the center conductor of the connector may be electrically connected to the antenna array via a conductive elastomer. The at least one waveguide of the connector may include a plurality of waveguides, and the connector may be electrically connected to the antenna array via a grid of conductive elastomer pins, with each pin disposed in electrical connection with a respective center conductor of the plurality of coaxial waveguides.

[0008] In yet a further of its aspects the present invention may provide a connectorized circuit board assembly, comprising a connector in accordance with the present invention as described herein, and comprising a circuit board disposed in the mounting feature of the connector. The circuit board may be electrically connected to the center conductor. In the connectorized circuit board assembly, the first end of the center conductor of the connector may be electrically connected to a selected electrical trace of the circuit board. The first end of the center conductor of the connector may be soldered to a selected electrical trace of the circuit board.

[0009] The present invention may also provide an antenna system, comprising an antenna array; a stiffener sheet having a conductive feedthrough extending therethrough, the feedthrough disposed in electrical communication with the antenna

array; and at least one circuit board having upper and lower opposing planar surfaces and having an edge extending between the opposing planar surfaces. The edge may include a smaller surface area than the surface area of either of the opposing surfaces with a metallization on the edge. The metallization may be electrically connected to the conductive feedthrough of the stiffener sheet to provide electrical connection between the circuit board and the antenna array.

[0010] Further, the present invention may provide a method for creating a connector configured to provide physical and electrical connection to a circuit board having conductive traces. The method may include depositing a plurality of layers over a substrate, wherein the layers comprise one or more of conductive, non-conductive and sacrificial materials; patterning the layers of conductive, non-conductive and sacrificial material to define the structure of the connector which includes a mounting feature for receiving an edge of the circuit board, and at least one coaxial waveguide disposed within the connector. The waveguide may include a center conductor having a first end, the first end configured to be electrically connected to a conductive trace of the circuit board. The method may further include removing the sacrificial material to provide the connector. The plurality of layers may be disposed parallel to a longitudinal axis of the center conductor or may be disposed perpendicular to a longitudinal axis of the center conductor. The at least one coaxial waveguide may include an air spaced coaxial waveguide. The method may be performed by techniques adapted from those disclosed in the incorporated PolyStrata[®] art.

Brief Description of the Drawings

[0011] The foregoing summary and the following detailed description of exemplary embodiments of the present invention may be further understood when read in conjunction with the appended drawings, in which:

[0012] Figure 1 schematically illustrates an exploded isometric view of an exemplary configuration of a microwave/millimeter-wave component to circuit board connector in accordance with the present invention in which antenna array elements are electrically connected with driving electronics provided on printed circuit boards;

[0013] Figure 2 schematically illustrates isometric views, partially assembled and assembled, of the connector of Fig. 1;

[0014] Figure 3 schematically illustrates a fragmentary view of the structure of Fig. 1; and

[0015] Figure 4 schematically illustrates a fragmentary exploded isometric view of a further exemplary configuration of a microwave/millimeter-wave component to circuit board connection in accordance with the present invention in which antenna array elements are electrically connected with an edge connected printed circuit board.

Detailed Description of the Invention

[0016] Referring now to the figures, wherein like elements are numbered alike throughout, Figures 1–3 schematically illustrate an exemplary system, in this case an antenna array system 100, which depicts various aspects of connectors 150 in accordance with the present invention. Specifically, among the features illustrated are how connectors 150 of the present invention may be fixedly attached to circuit boards 160, such as by solder, and removably attached to microwave/millimeter-wave components, such as an antenna array 120 with aperture array 110.

[0017] More specifically, the connector 150 may include a slot 152 into which an edge of the printed circuit board 160 may be inserted, Fig. 3. The connector 150 may include a coaxial waveguide 155 having a center conductor 154. The coaxial waveguide 155 may also be termed a 3D coaxial waveguide 155, due to its three-dimensional routing through the body of the connector 150. As such, the center conductor 154 may be ground shielded on all four sides in the case of rectacoax and may provide optimum isolation between two adjacent signal lines (each surrounded by metal shielding). The center conductor 154 may have other shapes than rectangular. A selected end of the center conductor 154 proximate the slot 152 may be soldered to a solder pad 162 on the circuit board 160, where the solder pad 162 is electrically connected to a conductive trace 163 of the circuit board 160. Thus, the connector 150 soldered onto the circuit board 160 may provide a connectorized circuit board assembly 165. Other suitable means for fixedly attaching the connector 150 to the circuit board 160 may be provided, such as a conductive epoxy, for example. The circuit board 160 may include circuitry for controlling the antenna array 120.

[0018] As to the removable connection between the connector 150 and the antenna array 120, a conductive elastomer pin 141, such as one provided in a land grid array,

LGA 140, may be provided at the end of the connector 150 proximate the antenna array 120. The LGA 140 may include multiple forms of “separable” (i.e., removable as defined herein) interconnect between the stiffener 130 and/or the connector 150, including but not limited to: elastomer interconnects, metal spring interconnects, fuzz buttons, and/or diamond particle interconnect. In addition, the LGA 140 may include a hybrid of a separable interconnect and non-separable interconnect, such as solder and conductive epoxy. For example, the LGA 140 may include a separable compressive interconnection, such as a conductive elastomer, on one side of the LGA 140 and a ball grid array of solder bumps on the opposite side. Thus, for such a configuration the LGA 140 may separate from the remaining structure, but only on one side.

[0019] The conductive elastomer pin 141 may be disposed in registration and electrical contact with the center conductor 154 of the connector 150. The conductive elastomer pin 141 may be electrically connected to a corresponding conductive feedthrough 121 of the antenna array 120. Optionally, a stiffener 130 may be provided between the LGA 140 and the antenna array 120 to provide additional stiffness to the antenna array 120, if required. The stiffener 130 may be provided in the form of a metal sheet having a conductive feedthrough 131 extending therethrough. The conductive feedthrough 131 of the stiffener 130 may be electrically connected to the feedthrough 121 of the antenna array 120 as well as to the conductive elastomer pin 141, thus completing electrical connection between the solder pad 162 of the circuit board 160 and the antenna array 120.

[0020] As further illustrated in Fig. 1, a plurality of connectors 150 and a plurality of circuit boards 160 may be electrically connected to one another to drive the entire antenna array 120. More specifically, in the context of the antenna array system 100, a system circuit board 170 may be provided which includes circuitry for communication with the antenna array 120 as well as other optional components for controlling a broader system of which the antenna array system 100 is but one component. The system circuit board 170 may be connected to the circuit boards 160 via an array of connectors 150 via an LGA 140, in a manner similar to that described above with regard to Fig. 3. To permit a plurality of circuit boards 160 to be electrically connected to an array of antenna elements 120, each connector element

150 as illustrated in Fig. 3, may be provided as a grid of elements as illustrated in Figs. 1, 2. In particular, with reference to Fig. 2, the array of connectors 150 may be assembled from a plurality of individual one-dimensional connector strips 152, each strip 152 including a plurality of connector elements 150. The connector strips 152 may be configured to slide together to form the array of connectors 150, and additional rails 154 may be provided along the edges of the strips 152 to help secure them in place. The antenna array system 100 may also include side panels 180, 182 that may encase, support, and shield the system 100.

[0021] One or more of the connector elements 150, connector strips 152, stiffener 130, and antenna array 120 may contain a plurality of sequential (e.g., laminated) metal layers, such as provided by a multilayer build process such as PolyStrata[®] multilayer build processing/technology. As such, the connector elements 150, connector strips 152, stiffener 130, and antenna array 120 may each be a unitary monolithic structure comprised of the sequential layers. The layers of the connector 150 (or connector strips 152) may be oriented either perpendicular to, or parallel to, a longitudinal axis of the center conductor(s) 152 of the connector 150 (or connector strips 152). Similarly, layers of the antenna array 120 may be oriented either perpendicular to, or parallel to, a longitudinal axis of the feedthroughs 121 of the antenna array 120.

[0022] Figure 4 schematically illustrates a further exemplary antenna system in accordance with the present invention, in which components 120, 130, 140, 170 may be removably attached to one another and may use edge metallization 173 of a circuit board 170, which can obviate the need for the connector 150 of Figs. 1–3. In particular, the antenna array 120 may be electrically connected to the conductive stiffener sheet 130, with the respective feedthroughs 121, 131 of the antenna array 120 and stiffener sheet 130 electrically connected to one another. The pin 141 of the LGA 140 may be electrically connected to the feedthrough 131 of the stiffener sheet 130. The circuit board 170 may differ from that shown in Fig. 3 in that a metallization 173 may be provided on the edge of the circuit board 170, and the metallization 173 may be electrically connected to the pin 141 of the LGA 140, thus completing the electrical circuit between the board 170 and the antenna array 120.

[0023] These and other advantages of the present invention will be apparent to those skilled in the art from the foregoing specification. Accordingly, it will be recognized by those skilled in the art that changes or modifications may be made to the above-described embodiments without departing from the broad inventive concepts of the invention. It should therefore be understood that this invention is not limited to the particular embodiments described herein, but is intended to include all changes and modifications that are within the scope and spirit of the invention as set forth in the claims.

Claims

What is claimed is:

1. A connector configured to provide physical and electrical connection to a circuit board having conductive traces, the connector comprising:
a mounting feature for receiving an edge of the circuit board; and
at least one coaxial waveguide disposed within the connector, the waveguide having a center conductor having a first end, the first end configured to be electrically connected to a conductive trace of the circuit board.
2. The connector of claim 1, wherein the connector comprises a plurality of sequential layers of a metal joined to provide a unitary monolithic structure.
3. The connector of claim 2, wherein the center conductor has a longitudinal axis and the plurality of layers are disposed perpendicular to the longitudinal axis.
4. The connector of claim 2, wherein the center conductor has a longitudinal axis and the plurality of layers are disposed parallel to the longitudinal axis.
5. The connector of any one of the preceding claims, wherein the at least one coaxial waveguide comprises an air spaced coaxial waveguide.
6. The connector of any one of the preceding claims, wherein the mounting feature is a slot.
7. The connector of any one of the preceding claims, wherein the at least one coaxial waveguide comprises a plurality of waveguides.
8. An antenna system, comprising:
an antenna array;
a connector of any one of the preceding claims, the center conductor thereof electrically connected to the antenna array; and
at least one circuit board disposed in the mounting feature, the circuit board electrically connected to the center conductor of the connector to provide electrical connection between the circuit board and the antenna array.
9. The antenna system of claim 8, wherein the antenna array is removably attached to the connector.

10. The antenna system of any one of claims 8–9, wherein the antenna array comprises a plurality of sequential layers of a metal joined to provide a unitary monolithic structure.
11. The antenna system of any one of claims 8–10, wherein the antenna array includes a conductive feedthrough, the conductive feedthrough electrically connected to the center conductor of the connector.
12. The antenna system of any one of claims 8–11, wherein the first end of the center conductor of the connector is electrically connected to a selected electrical trace of the circuit board.
13. The antenna system of any one of claims 8–12, wherein the first end of the center conductor of the connector is soldered to a selected electrical trace of the circuit board.
14. The antenna system of any one of claims 8–13, wherein the circuit board comprises electronics for driving the antenna array.
15. The antenna system of any one of claims 8–14, wherein the center conductor of the connector is electrically connected to the antenna array via a conductive elastomer.
16. The antenna system of any one of claims 8–15, comprising an LGA electrically connected between the antenna array and the connector.
17. The antenna system of claim 16, wherein the LGA is removably connected to the antenna array.
18. The antenna system of any one of claims 16–17, wherein the LGA is soldered to the connector.
19. The antenna system of any one of claims 8–18, wherein at least one waveguide of the connector comprises a plurality of the waveguides, and the connector is electrically connected to the antenna array via a grid of conductive elastomer pins disposed between the connector and the antenna array, each pin disposed in electrical connection with a respective center conductor of the plurality of coaxial waveguides.

20. The antenna system of anyone of claims 8–19, wherein the at least one connector comprises a plurality of connectors and the at least one circuit board comprises a plurality of circuit boards.
21. A connectorized circuit board assembly, comprising the connector of any one of claims 1–7 and a circuit board disposed in the mounting feature, the circuit board electrically connected to the center conductor.
22. The connectorized circuit board assembly according to claim 21, wherein the first end of the center conductor of the connector is electrically connected to a selected electrical trace of the circuit board.
23. The connectorized circuit board assembly according to any one of claims 21–22, wherein the first end of the center conductor of the connector is soldered to a selected electrical trace of the circuit board.
24. An antenna system, comprising:
 - an antenna array;
 - a stiffener sheet having a conductive feedthrough extending therethrough, the feedthrough disposed in electrical communication with the antenna array; and
 - at least one circuit board having upper and lower opposing planar surfaces and having an edge extending between the opposing planar surfaces, the edge having a smaller surface area than the surface area of either of the opposing surfaces, the board having a metallization on the edge, the metallization electrically connected to the conductive feedthrough of the stiffener sheet to provide electrical connection between the circuit board and the antenna array.
25. The antenna system of claim 24, wherein the antenna array is removably attached to the conductive stiffener sheet.
26. The antenna system of any one of claims 24–25, wherein the antenna array includes a conductive feedthrough electrically connected to the conductive feedthrough of the conductive stiffener sheet.
27. The antenna system of any one of claims 24–26, wherein the circuit board comprises electronics for driving the antenna array.

28. The antenna system of any one of claims 24–27, wherein the conductive feedthrough of the stiffener sheet is electrically connected to the antenna array via a conductive elastomer.
29. The antenna system of any one of claims 24–28, wherein the stiffener sheet is electrically connected to the antenna array via a grid of conductive elastomer pins, each pin disposed in electrical connection with a respective feedthrough of the stiffener sheet.
30. A method for creating a connector configured to provide physical and electrical connection to a circuit board having conductive traces, comprising:
 - a. depositing a plurality of layers over a substrate, wherein the layers comprise one or more of conductive, non-conductive and sacrificial materials;
 - b. patterning the layers of conductive, non-conductive and sacrificial material to define the structure of the connector which includes a mounting feature for receiving an edge of the circuit board, and at least one coaxial waveguide disposed within the connector, the waveguide having a center conductor having a first end, the first end configured to be electrically connected to a conductive trace of the circuit board; and
 - c. removing the sacrificial material to provide the connector.
31. The method of claim 30, wherein the plurality of layers are disposed parallel to a longitudinal axis of the center conductor.
32. The method of claim 30, wherein the plurality of layers are disposed perpendicular to a longitudinal axis of the center conductor.
33. The method of any one of claims 30–32, wherein the at least one coaxial waveguide comprises an air spaced coaxial waveguide.

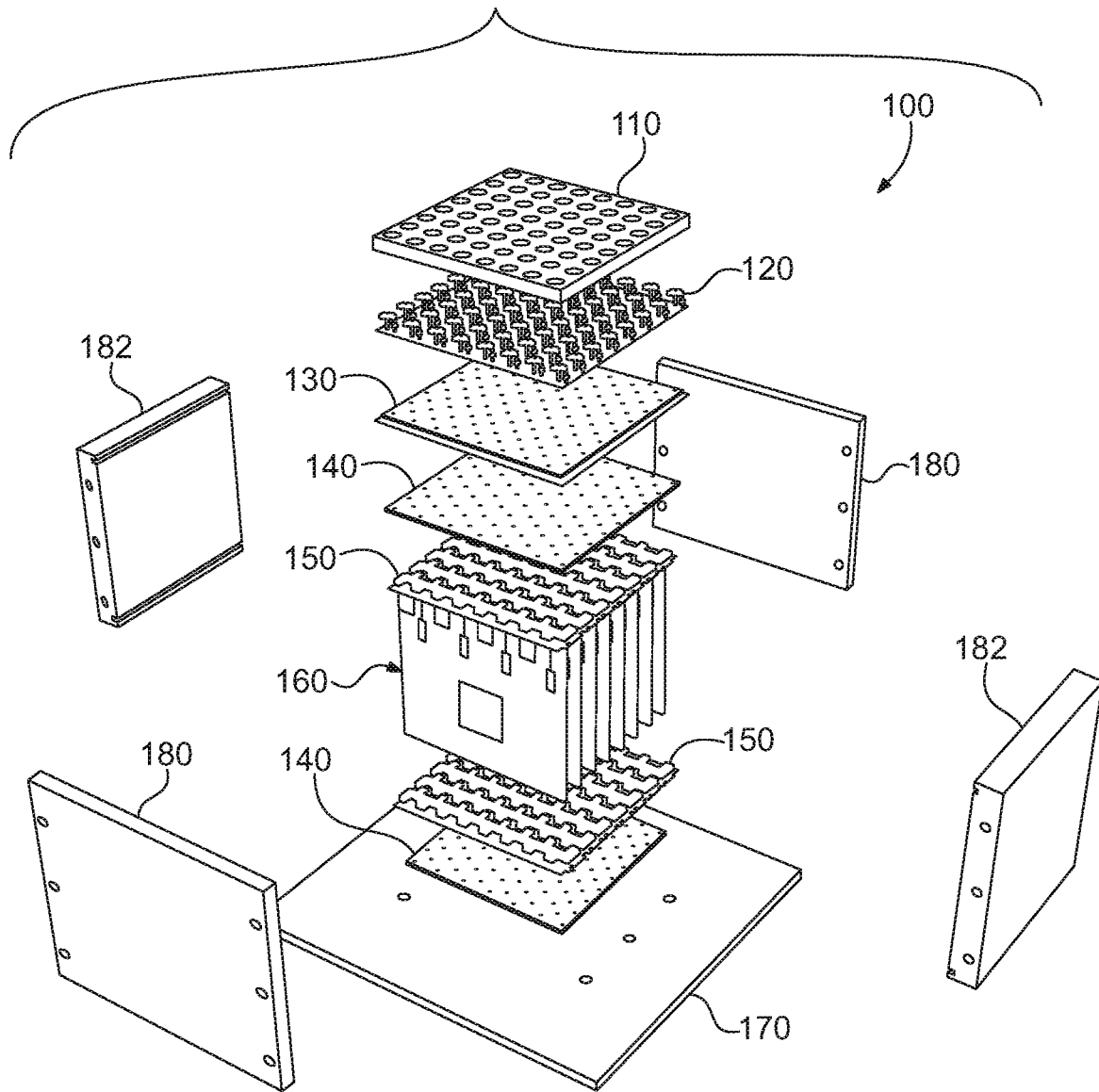


FIG. 1

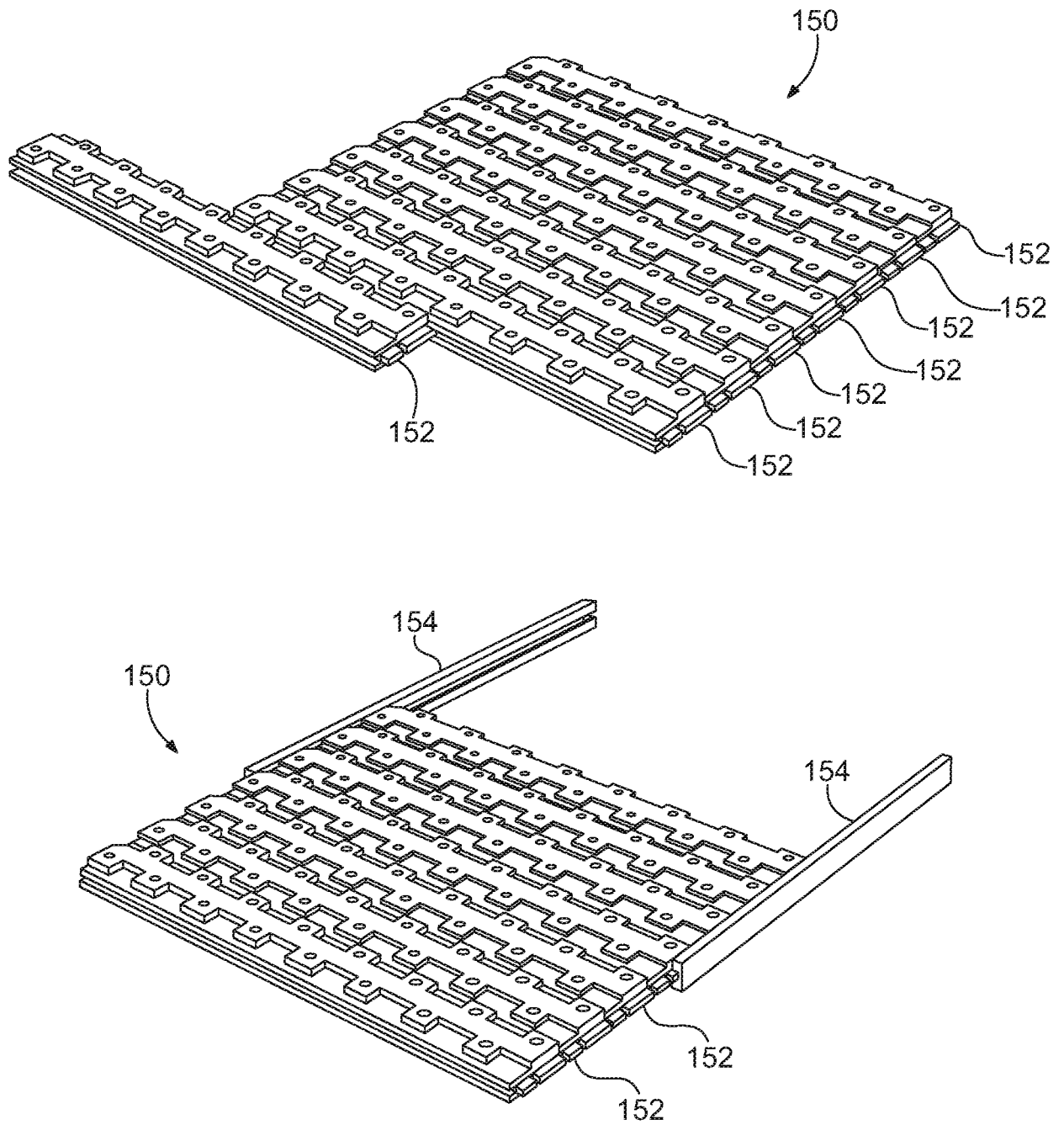


FIG. 2

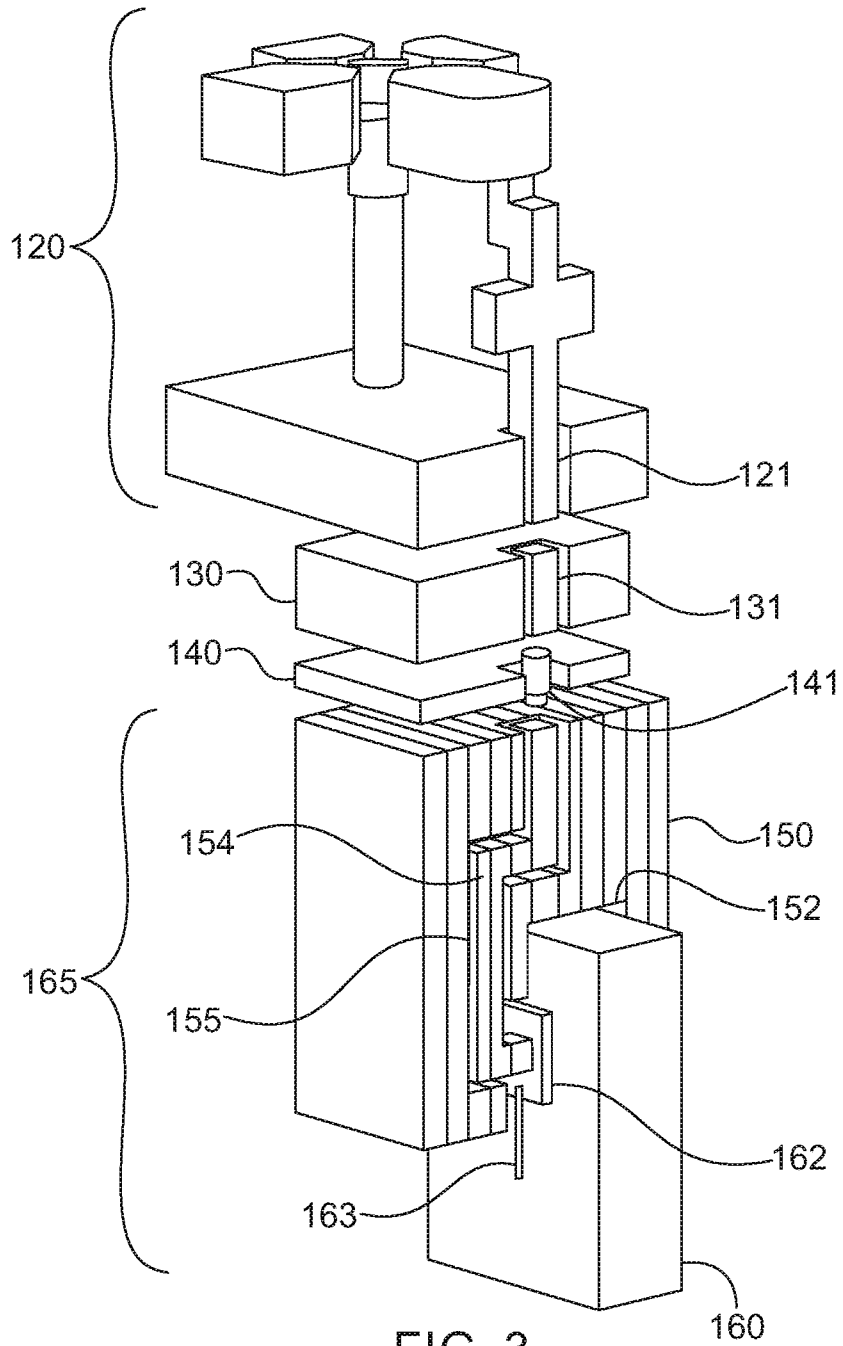


FIG. 3

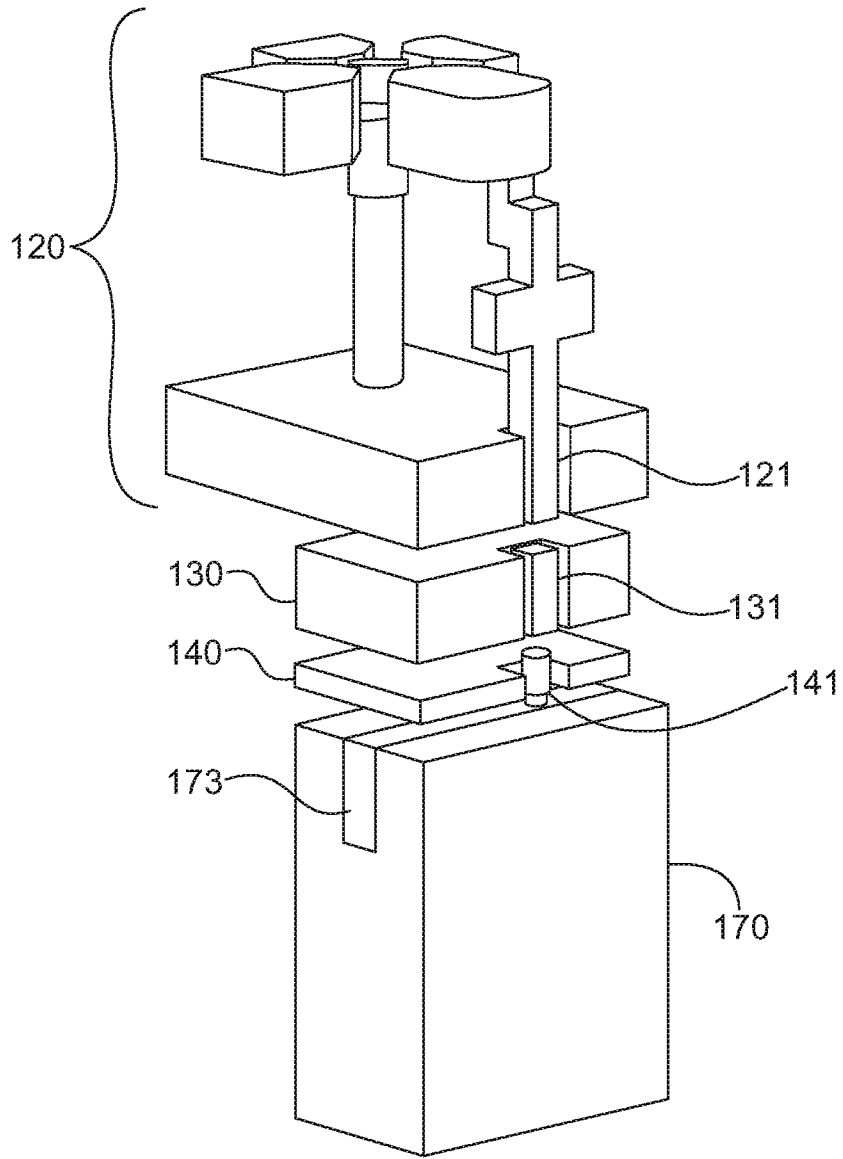


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US19/24838

A. CLASSIFICATION OF SUBJECT MATTER
 IPC - H01R 12/57, H01Q 1/22, 1/24, 13/08 (2019.01)
 CPC - H01R 12/57, H01Q 1/2291, 1/24, 13/08

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)

See Search History document

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

See Search History document

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

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016/0294035 A1 (NUVOTRONICS, INC.) 06 October, 2016; figures 2A-7 and 11; paragraphs [0003, 00015, 0050-0055, 0059, 0060].	1-5, 24-26, 30-33
X	US 2004/0119557 A1 (BARNES, H. et al.) 24 June 2004; figures 1A, 1C-1E; paragraphs [0024, 0031, 0034, 0035].	1
A	US 2017/0170592 A1 (NUVOTRONICS, INC.) 15 June 2017; entire document.	1-5, 24-26, 30-33
A	US 6,238,218 B1 (BAFFERT, J) 29 May 2001; entire document.	1-5, 24-26, 30-33
A	US 5,405,267 A (KOEGL, K. et al.) 11 April 1995; entire document.	1-5, 24-26, 30-33

Further documents are listed in the continuation of Box C.

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

26 May 2019 (26.05.2019)

Date of mailing of the international search report

11 JUN 2019

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US19/24838

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. Claims Nos.: 6-23, and 27-29
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.